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**Shiratsuchi et al.**

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(54) **LIGHTING SYSTEM HAVING LENSES FOR LIGHT SOURCES EMITTING RAYS AT DIFFERENT WAVELENGTHS**

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(52) **U.S. Cl.** ..... **362/268**; 362/230; 359/622

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362/297, 299-305, 308-311, 331-340, 230,  
362/231, 240, 241, 244; 359/620-624, 619-629  
See application file for complete search history.

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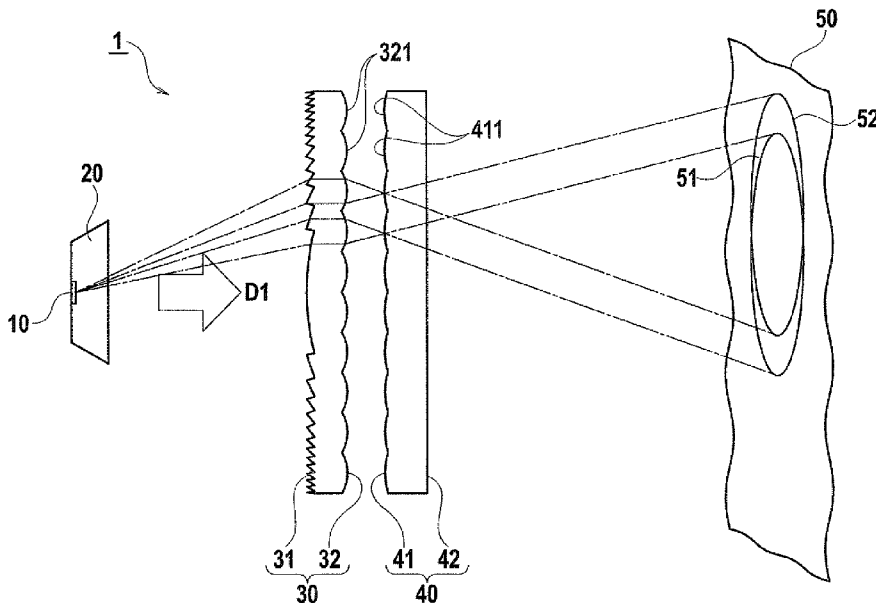
Chinese Office Action dated Dec. 19, 2008 corresponding to U.S. Appl. No. 11/538,894, filed Oct. 5, 2006.

*Primary Examiner*—Gunyoung T Lee  
(74) *Attorney, Agent, or Firm*—Turocy & Watson, LLP

(57) **ABSTRACT**

A lighting system includes a first light source emitting first light rays; a second light source emitting second light rays, a first lens side which refracts the first and second light rays and collimates the refracted light rays; a second lens side which includes a plurality of first lenticules and refracts the first and second light rays; and a third lens side which includes a plurality of second lenticules and refracts the first and second light rays refracted by the second lens side.

**8 Claims, 21 Drawing Sheets**



# US 7,648,256 B2

Page 2

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FIG. 1

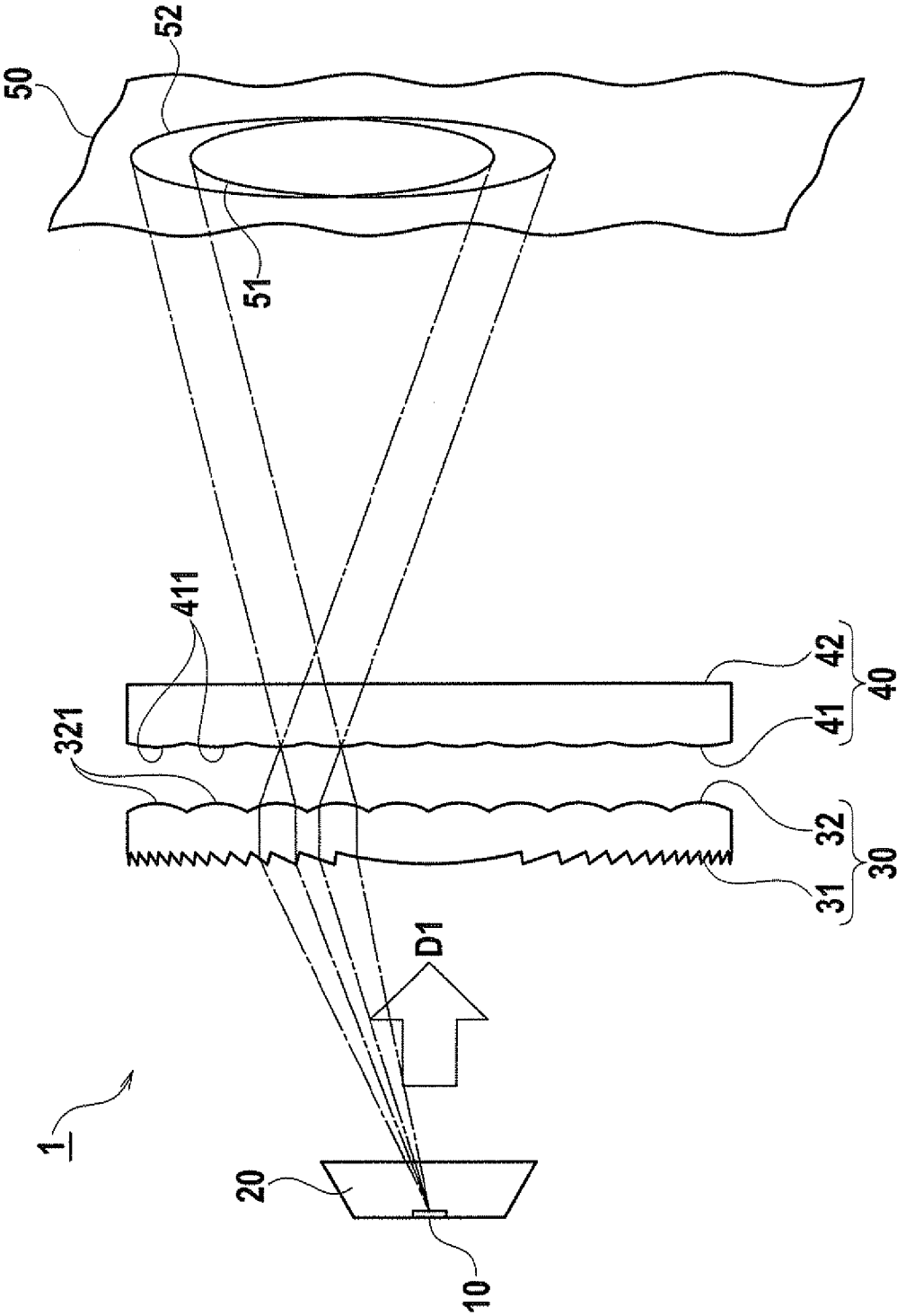


FIG. 2

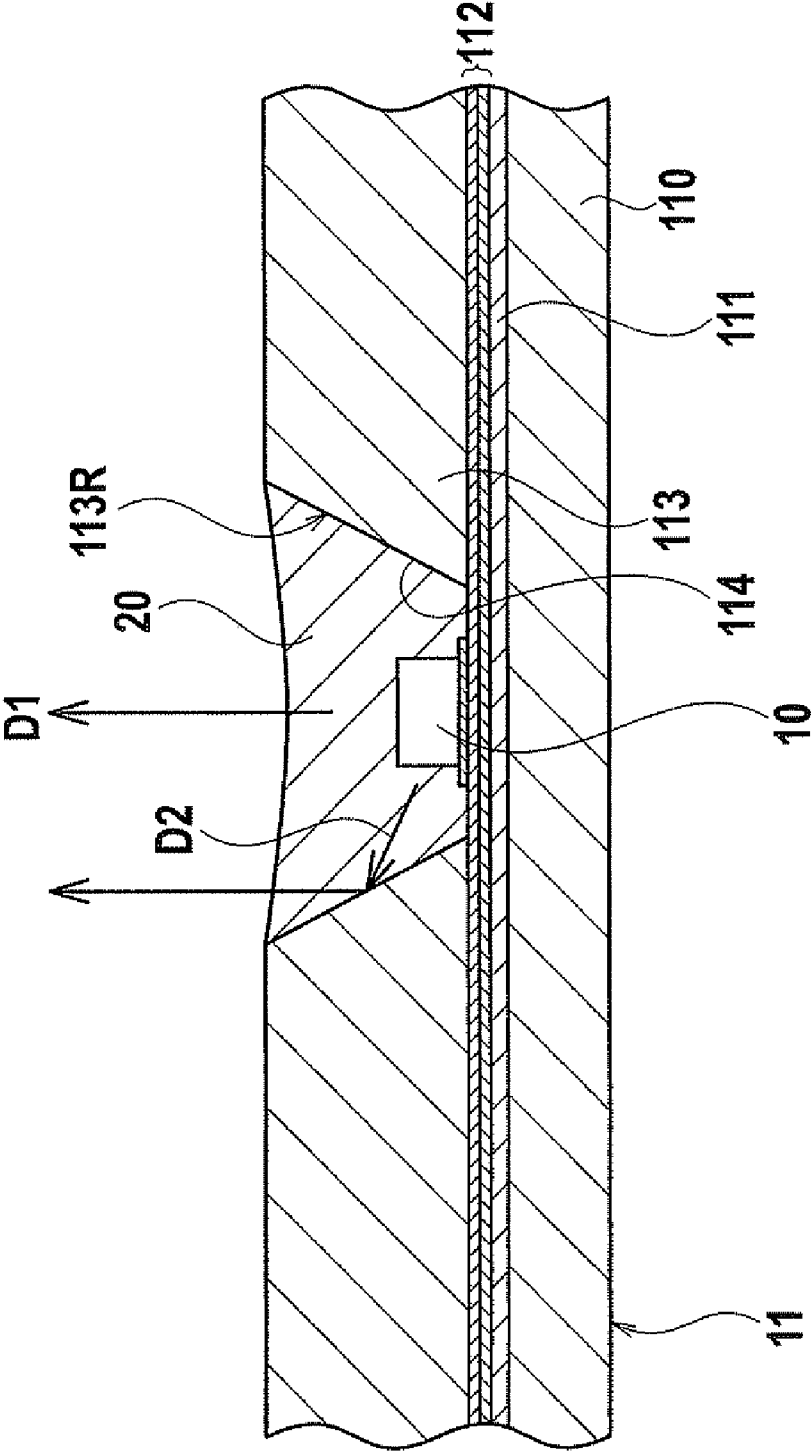


FIG. 3A

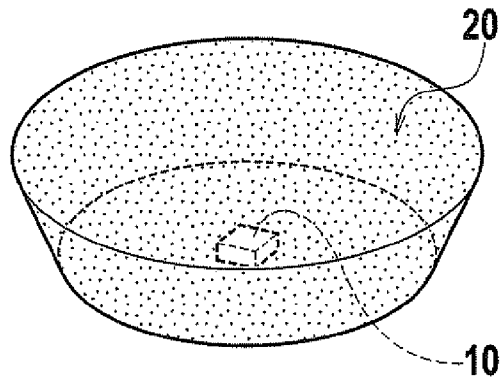


FIG. 3B

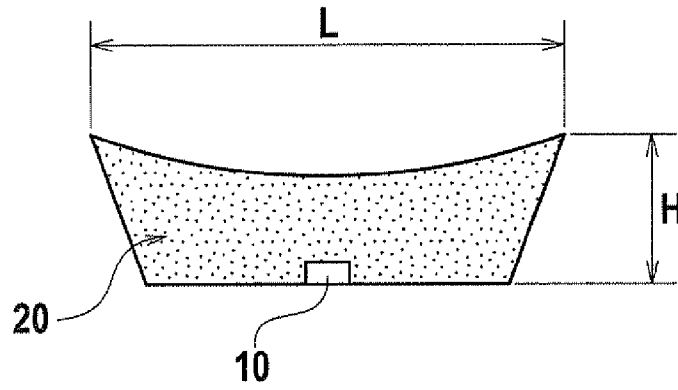


FIG. 3C

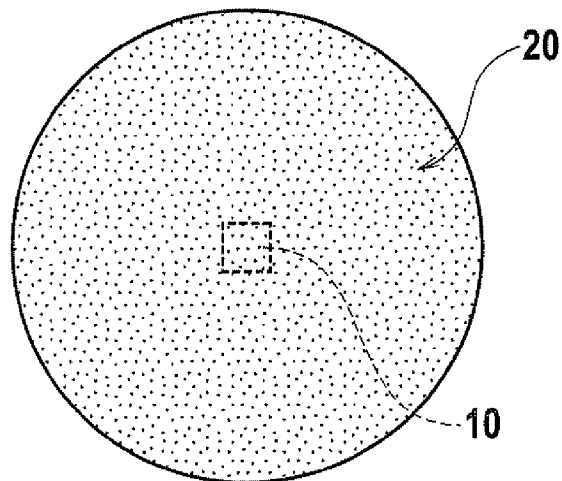


FIG. 4

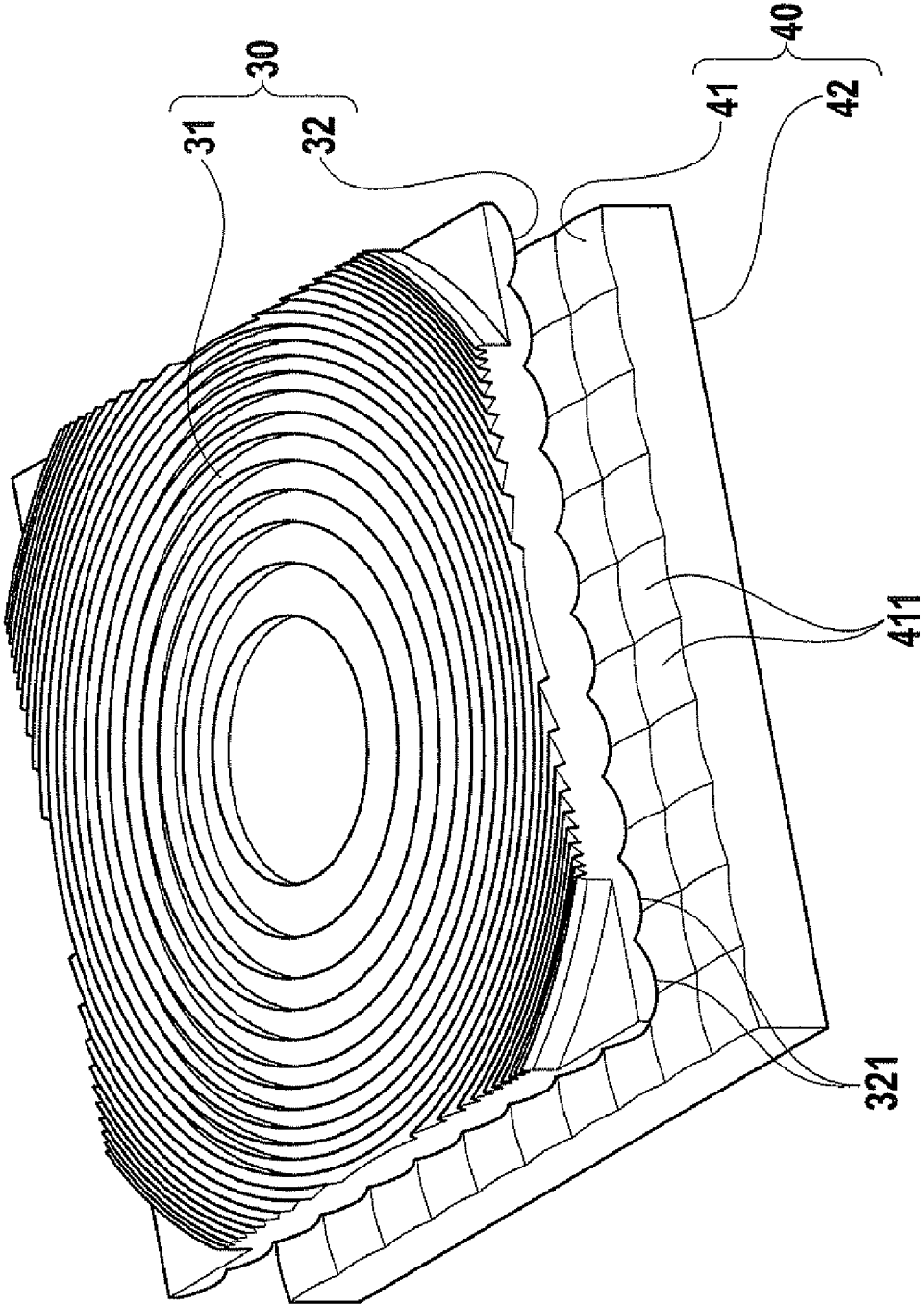


FIG. 5

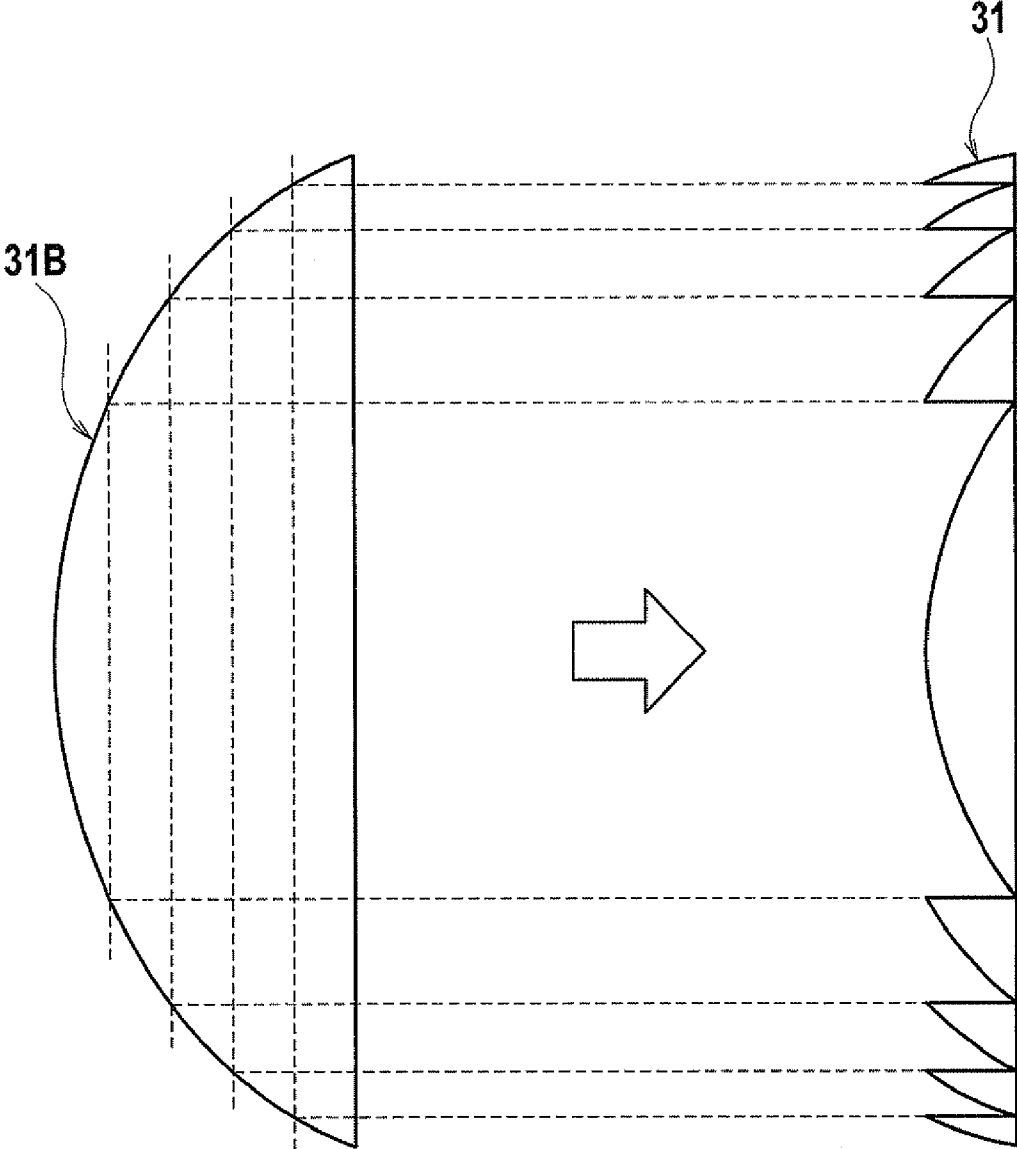


FIG. 6

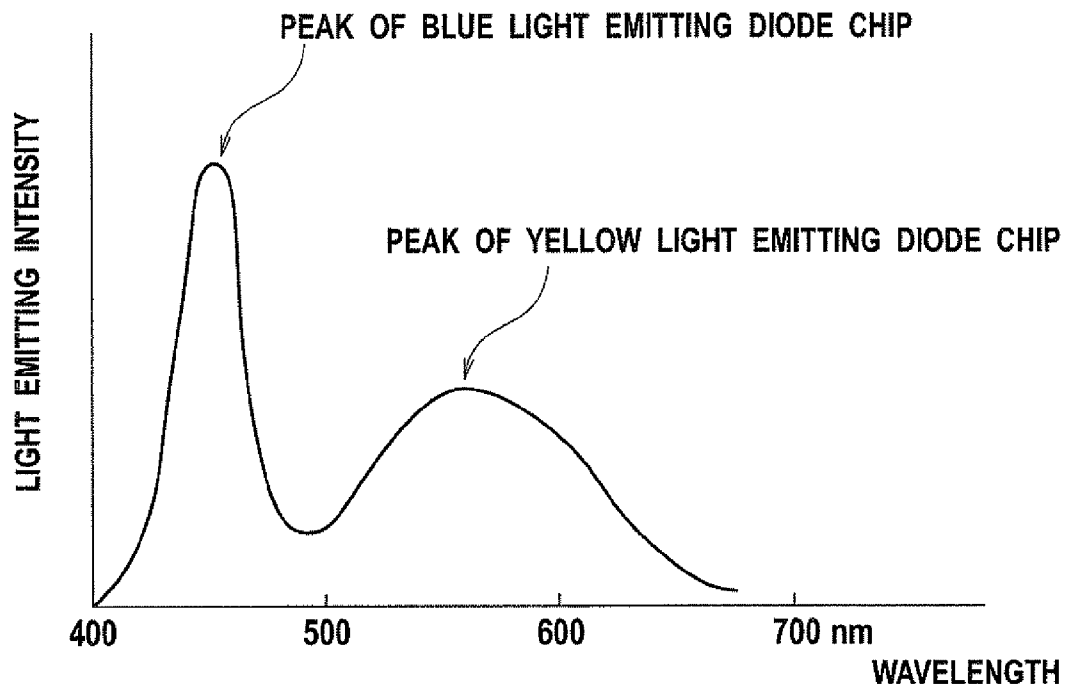




FIG. 7

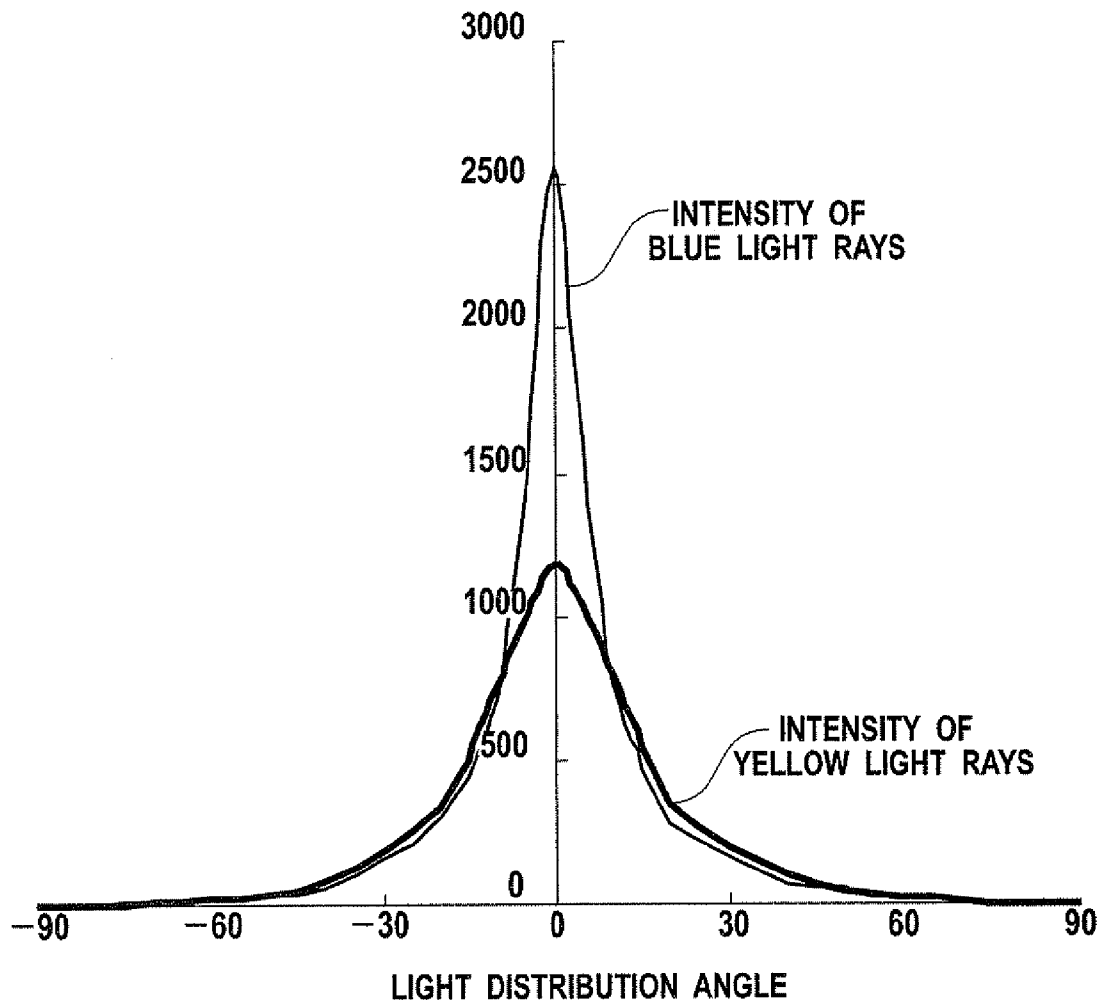


FIG. 8

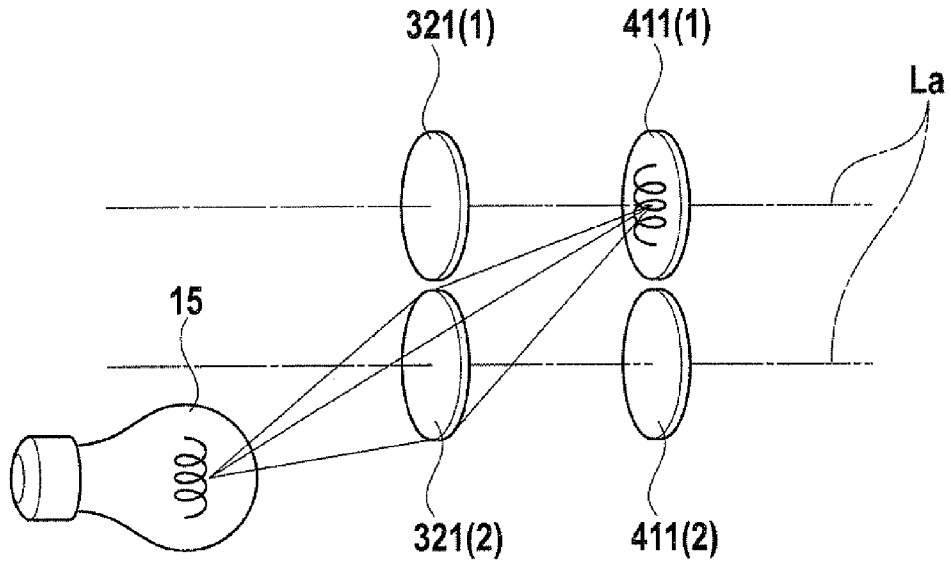


FIG. 9

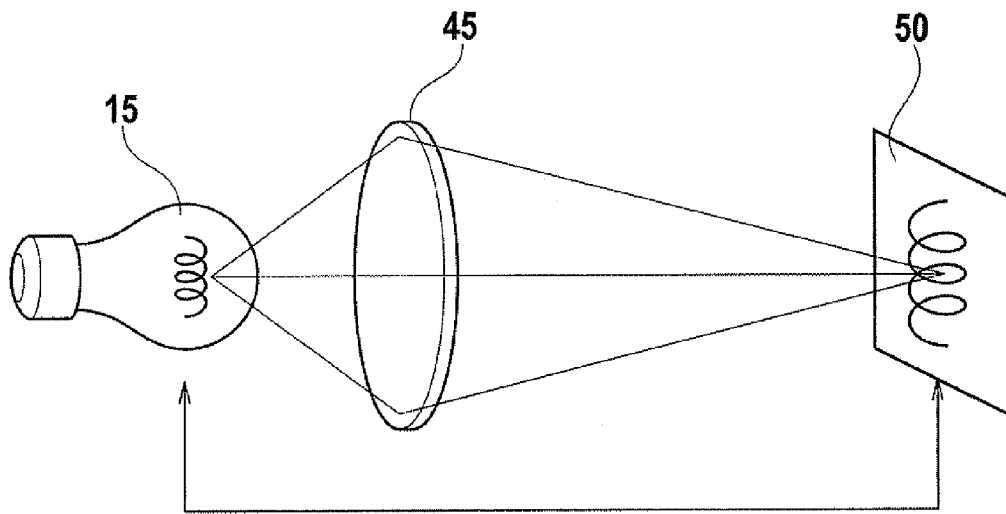


FIG. 10

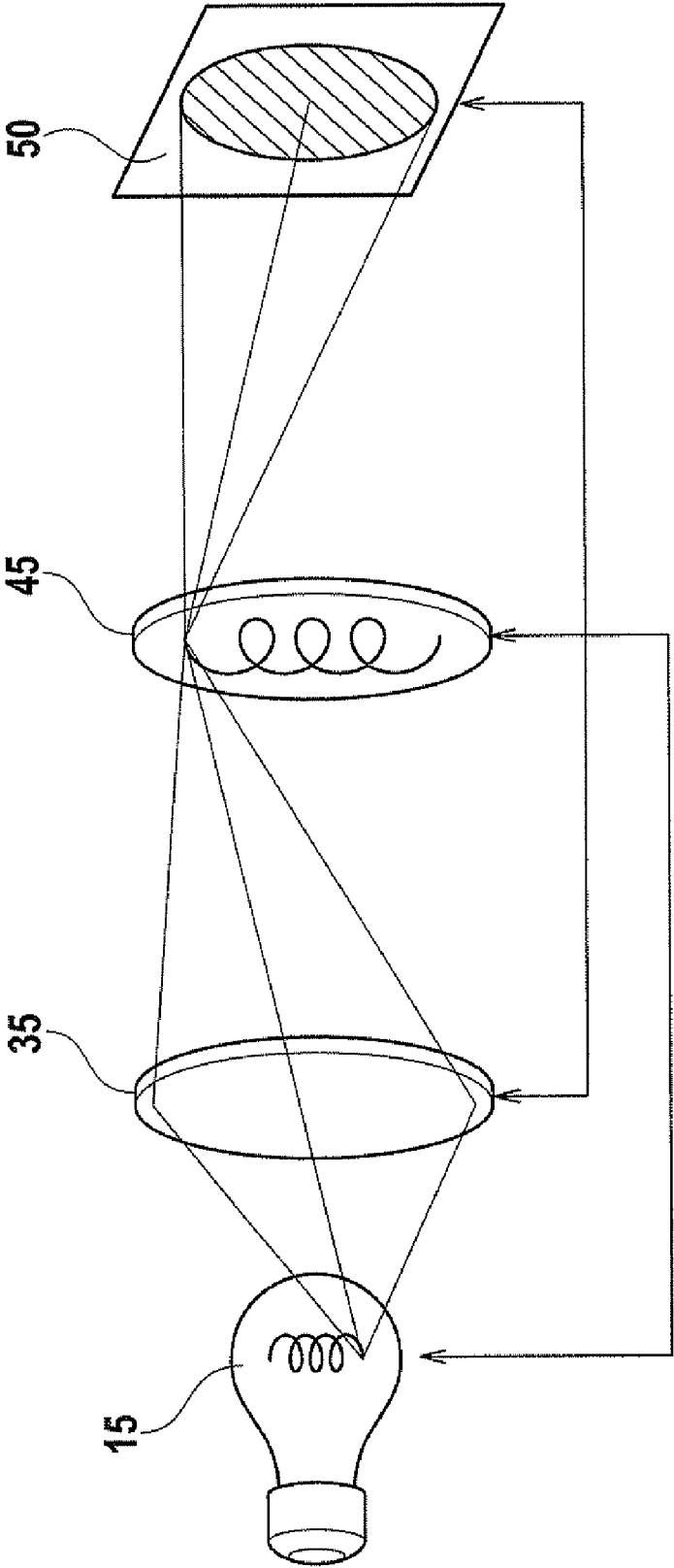


FIG. 11

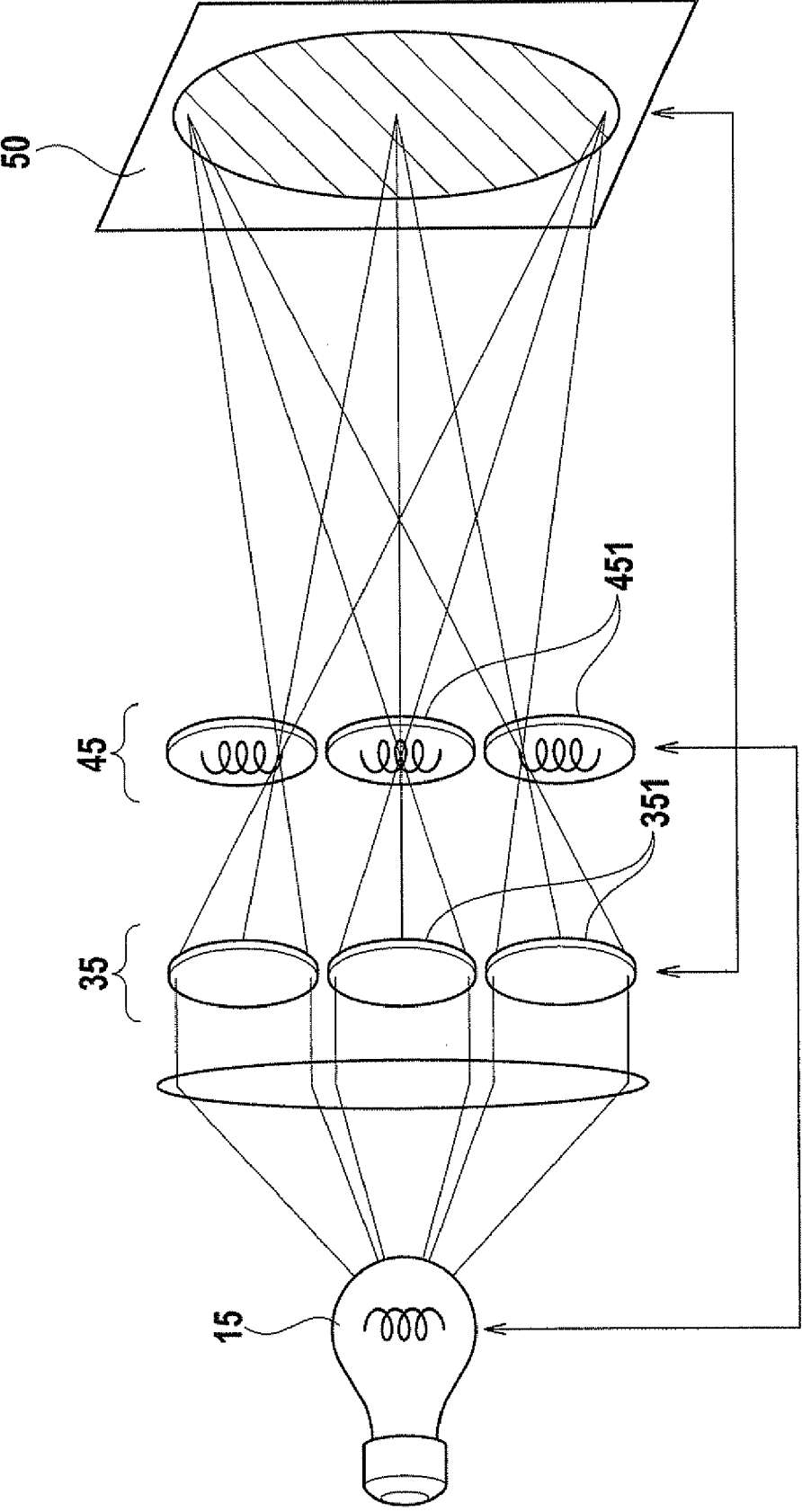


FIG. 12

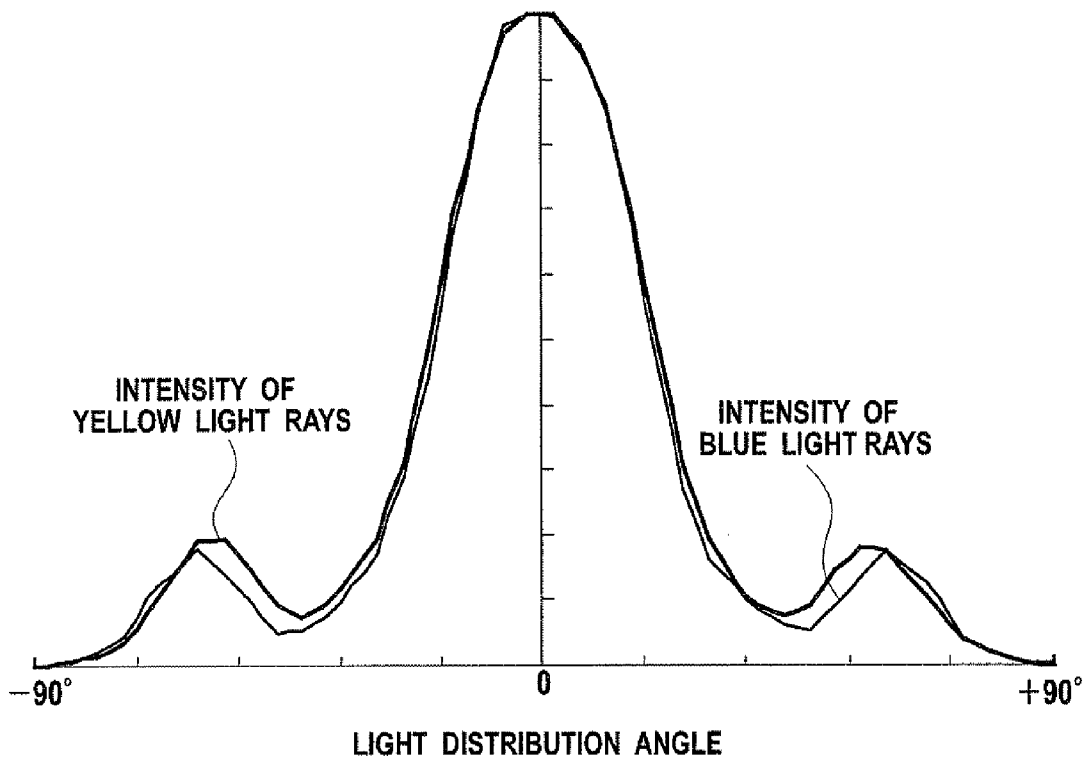


FIG. 13

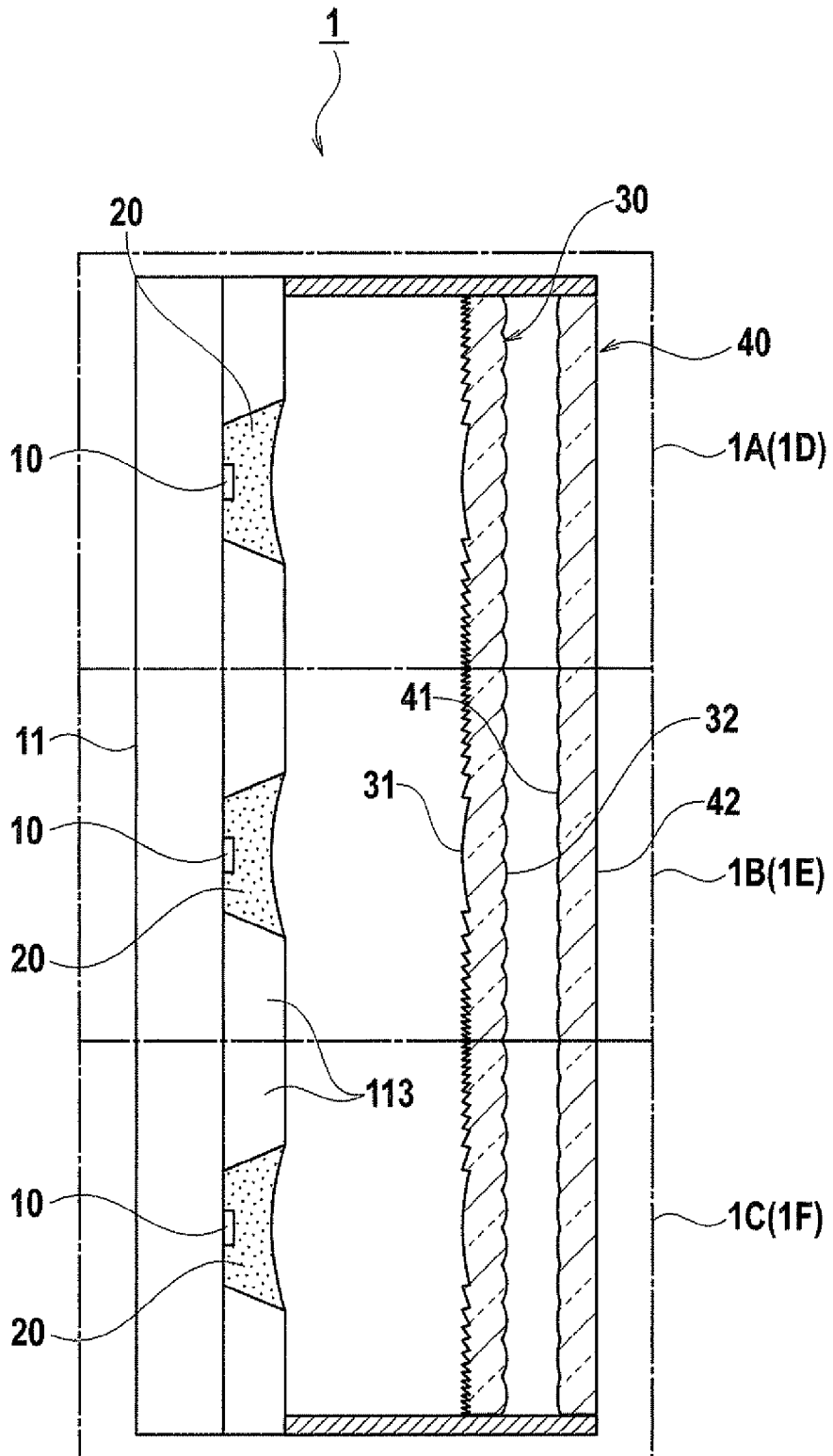


FIG. 14

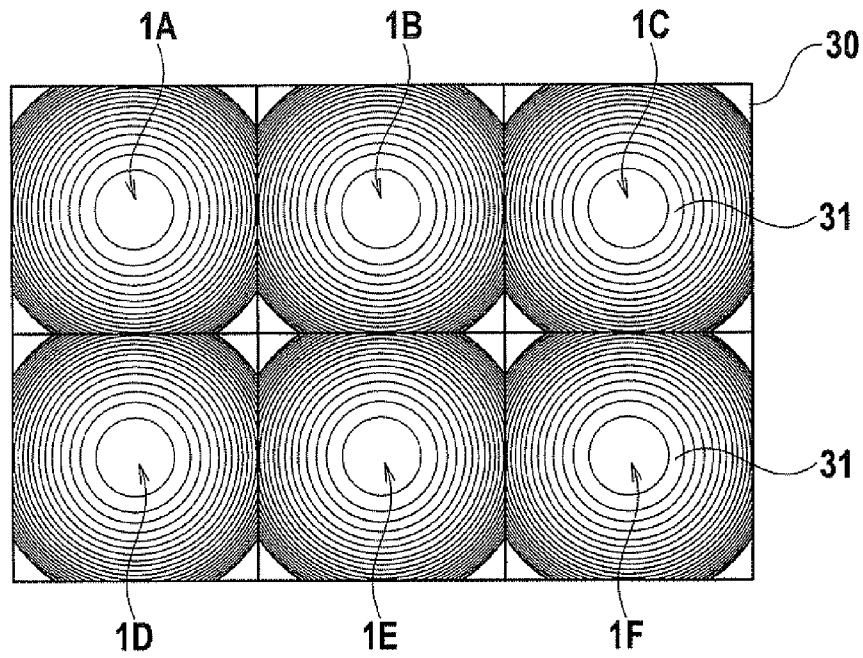


FIG. 15

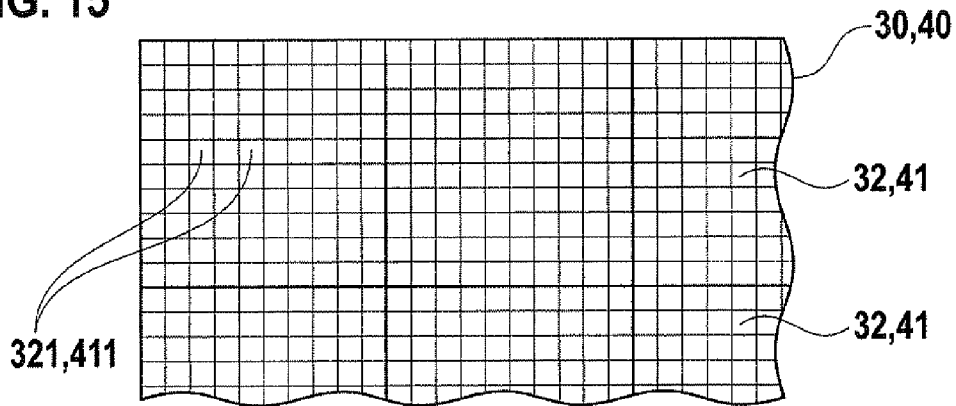


FIG. 16

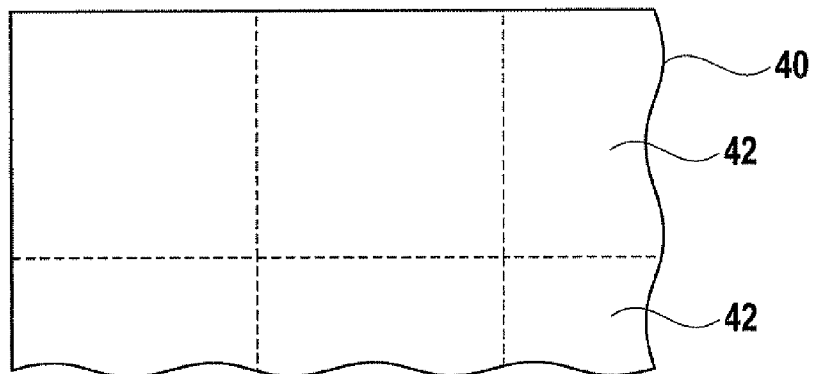


FIG. 17

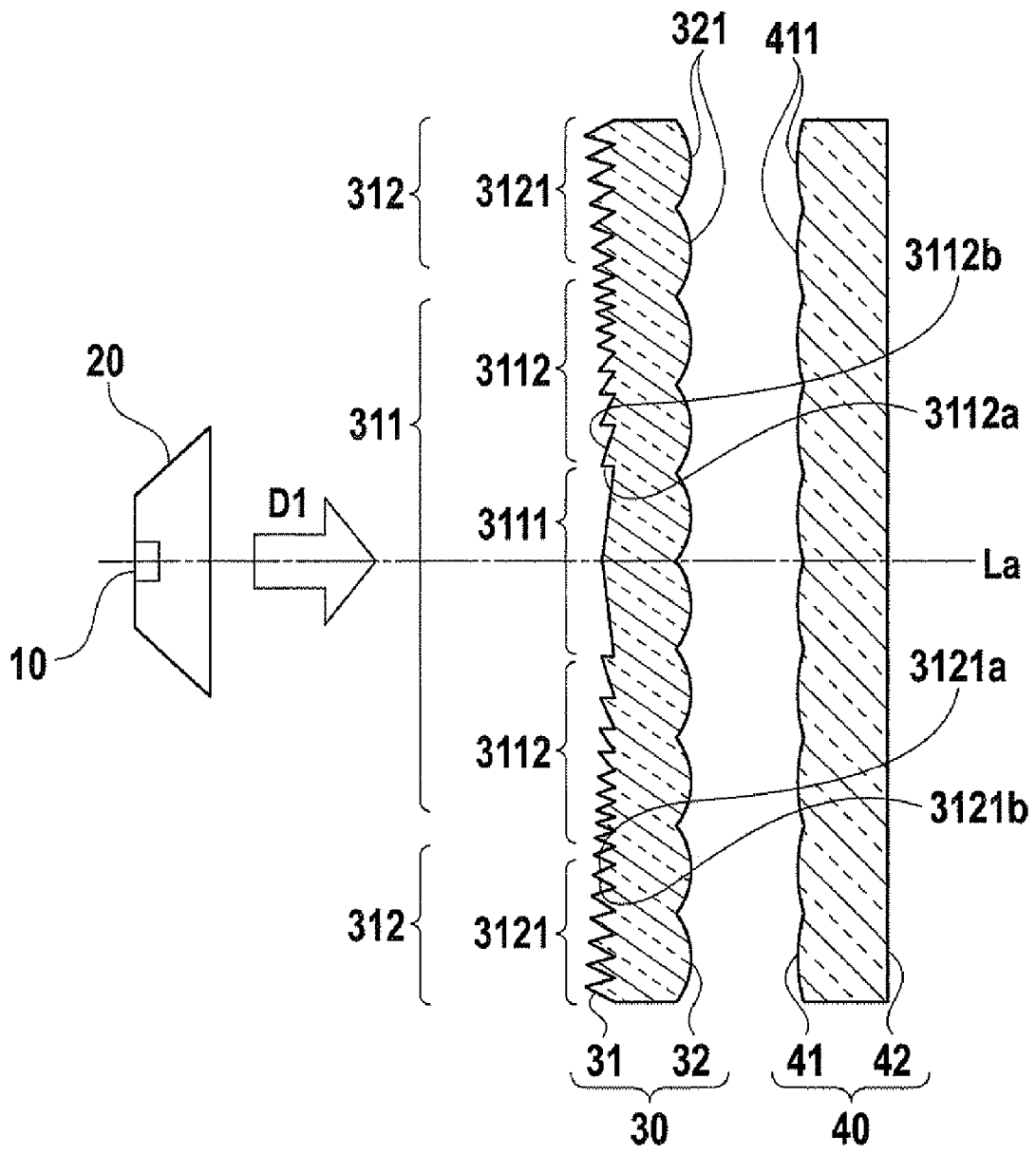




FIG. 18

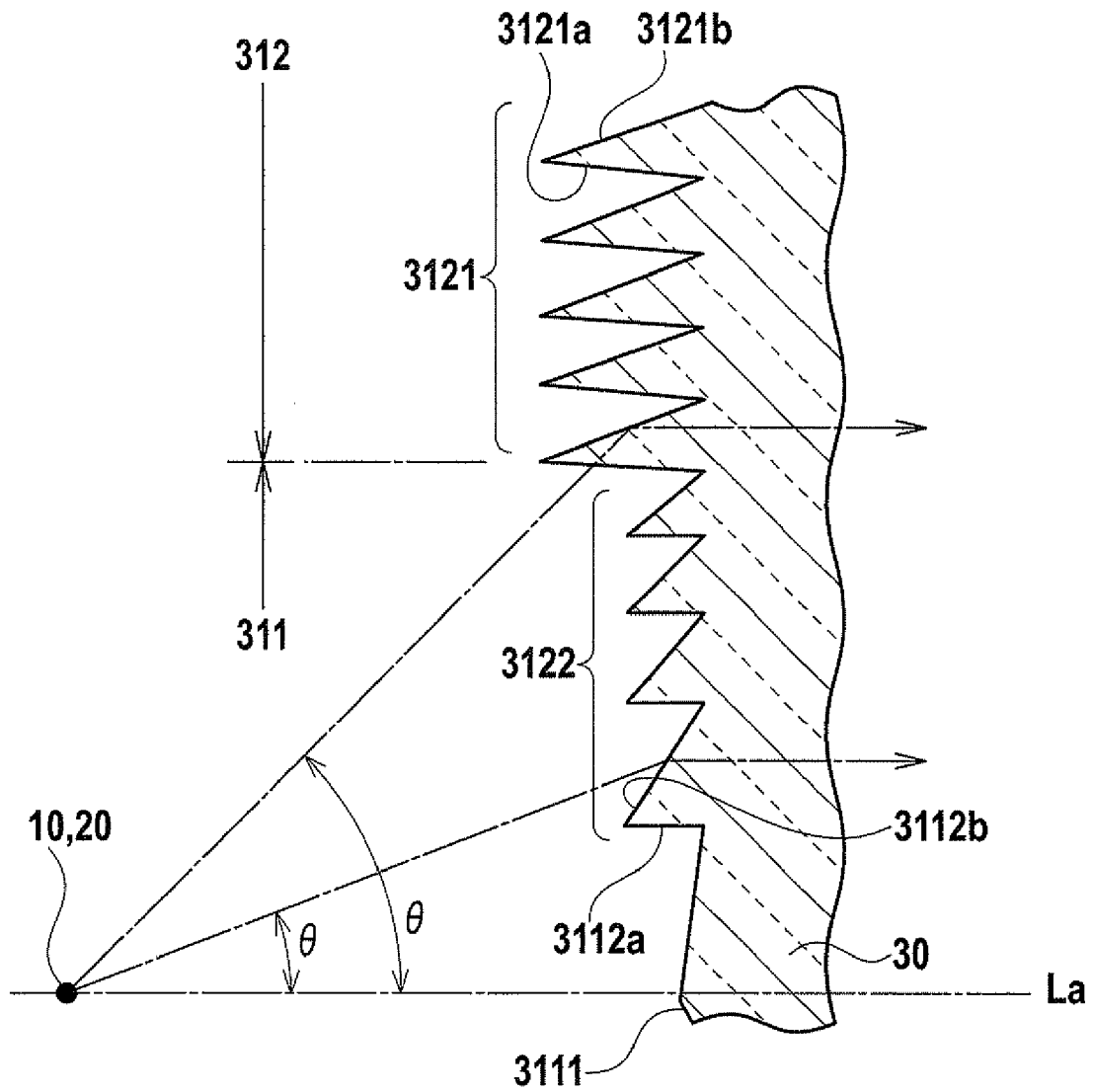


FIG. 19

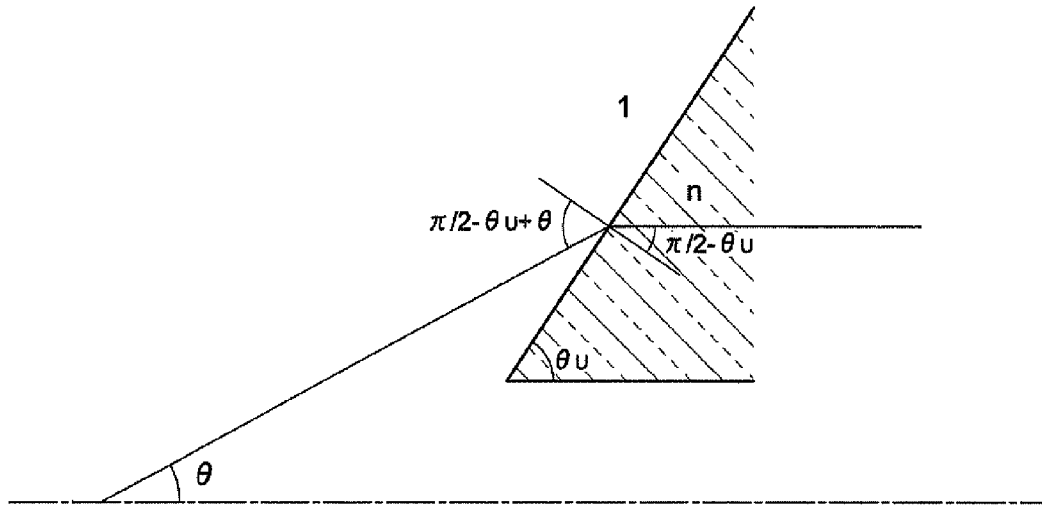


FIG. 20

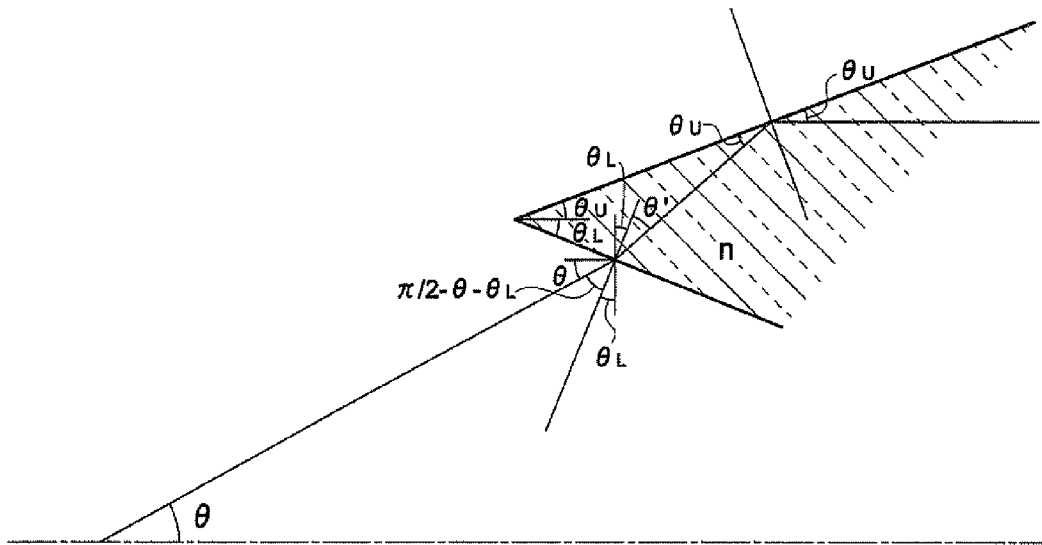


FIG. 21

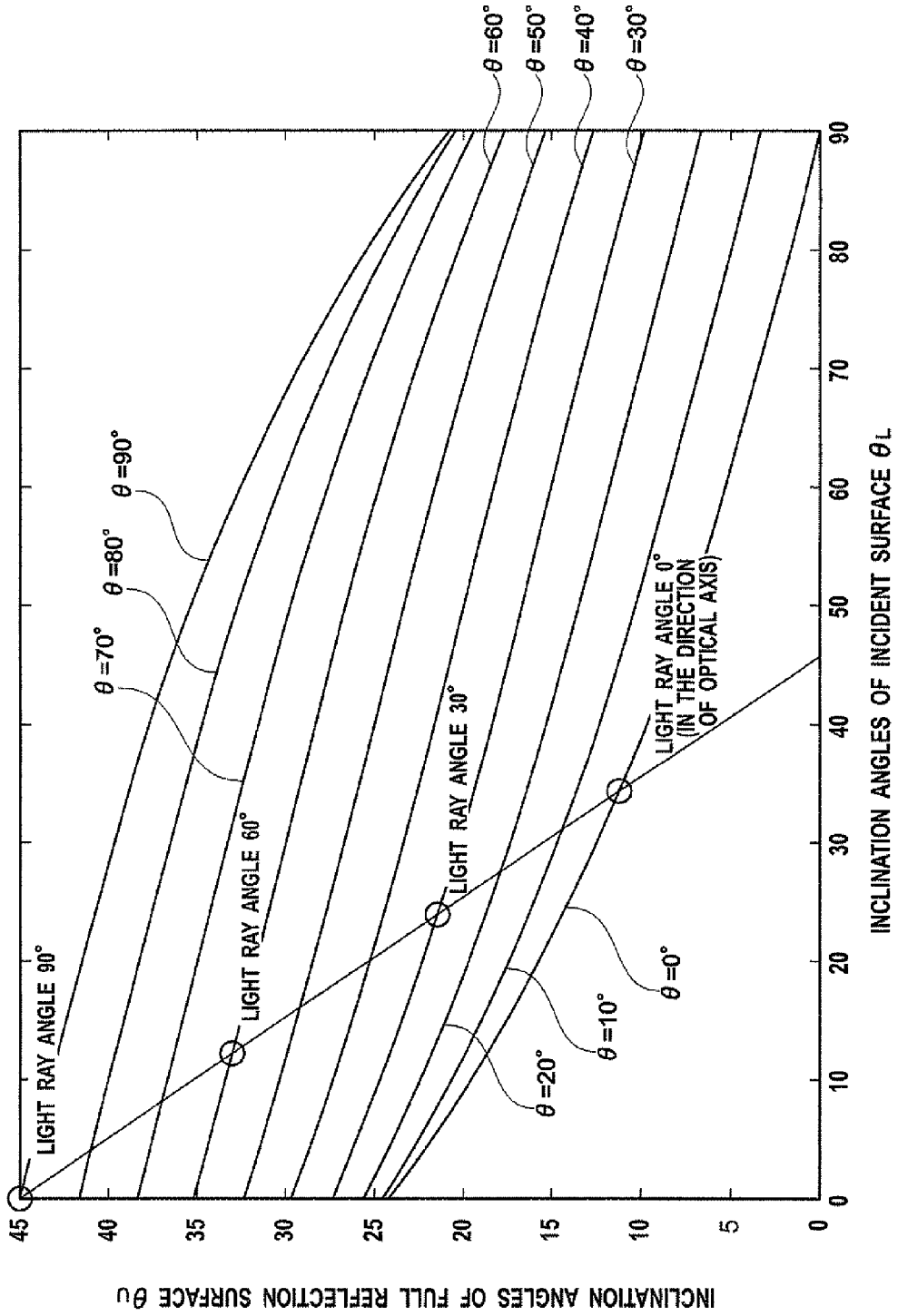


FIG. 22

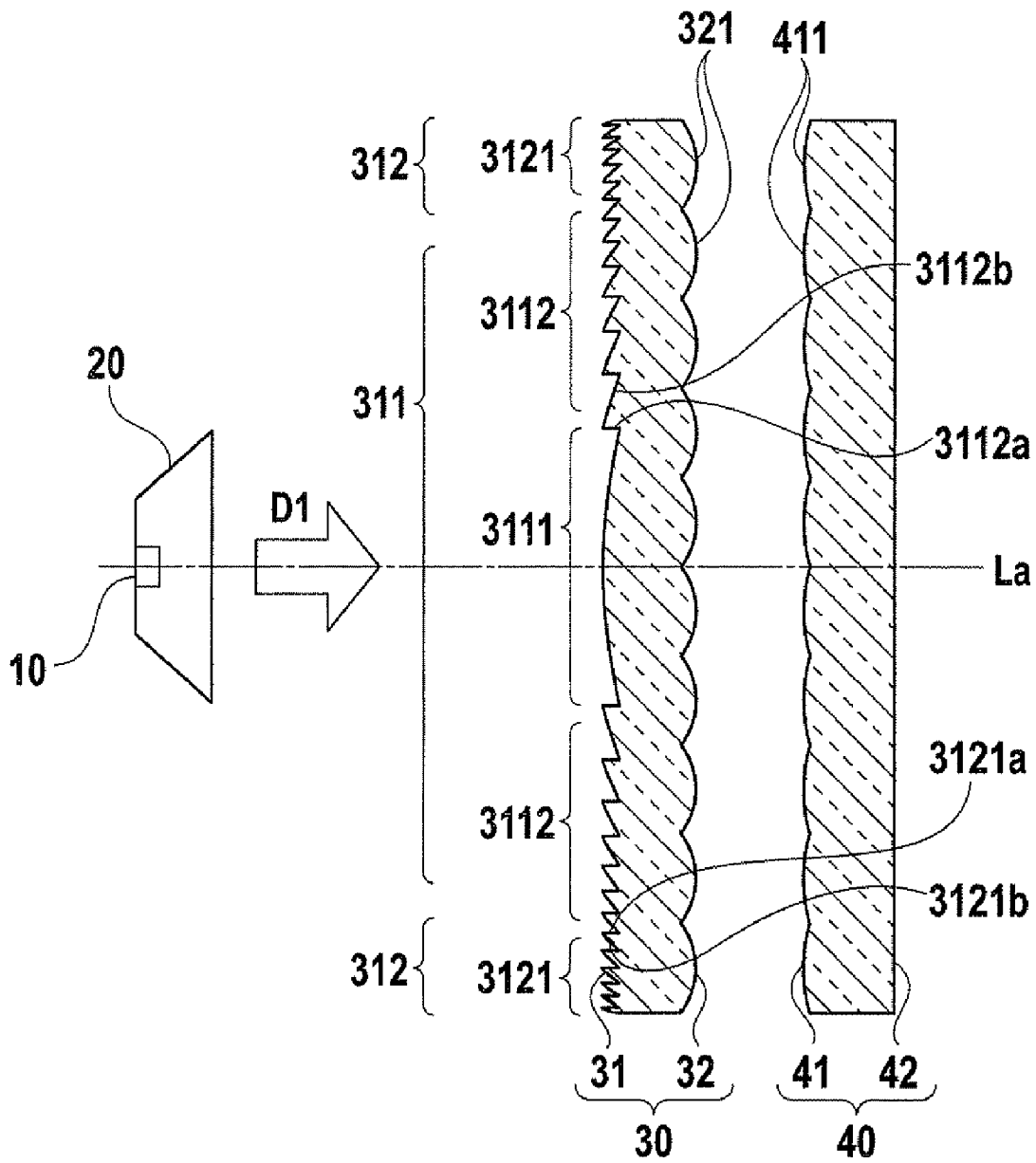


FIG. 23

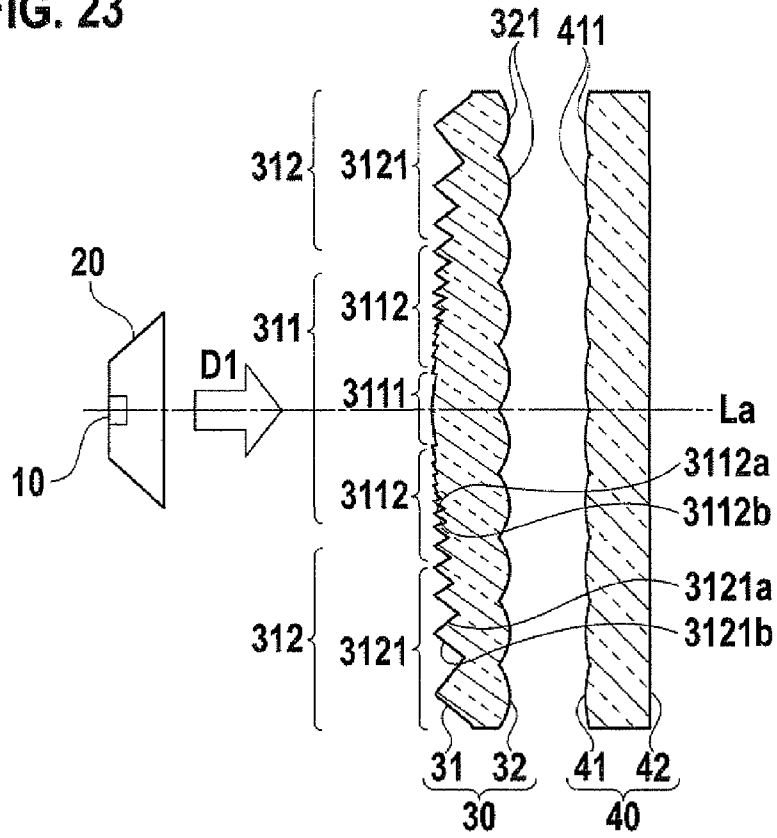


FIG. 24B

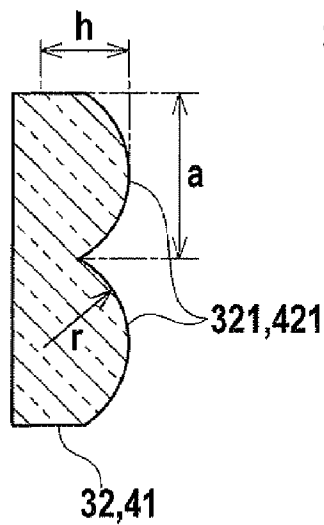


FIG. 24A

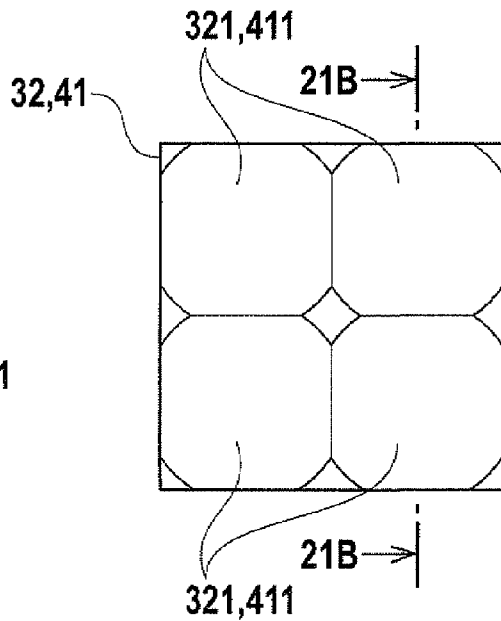


FIG. 25

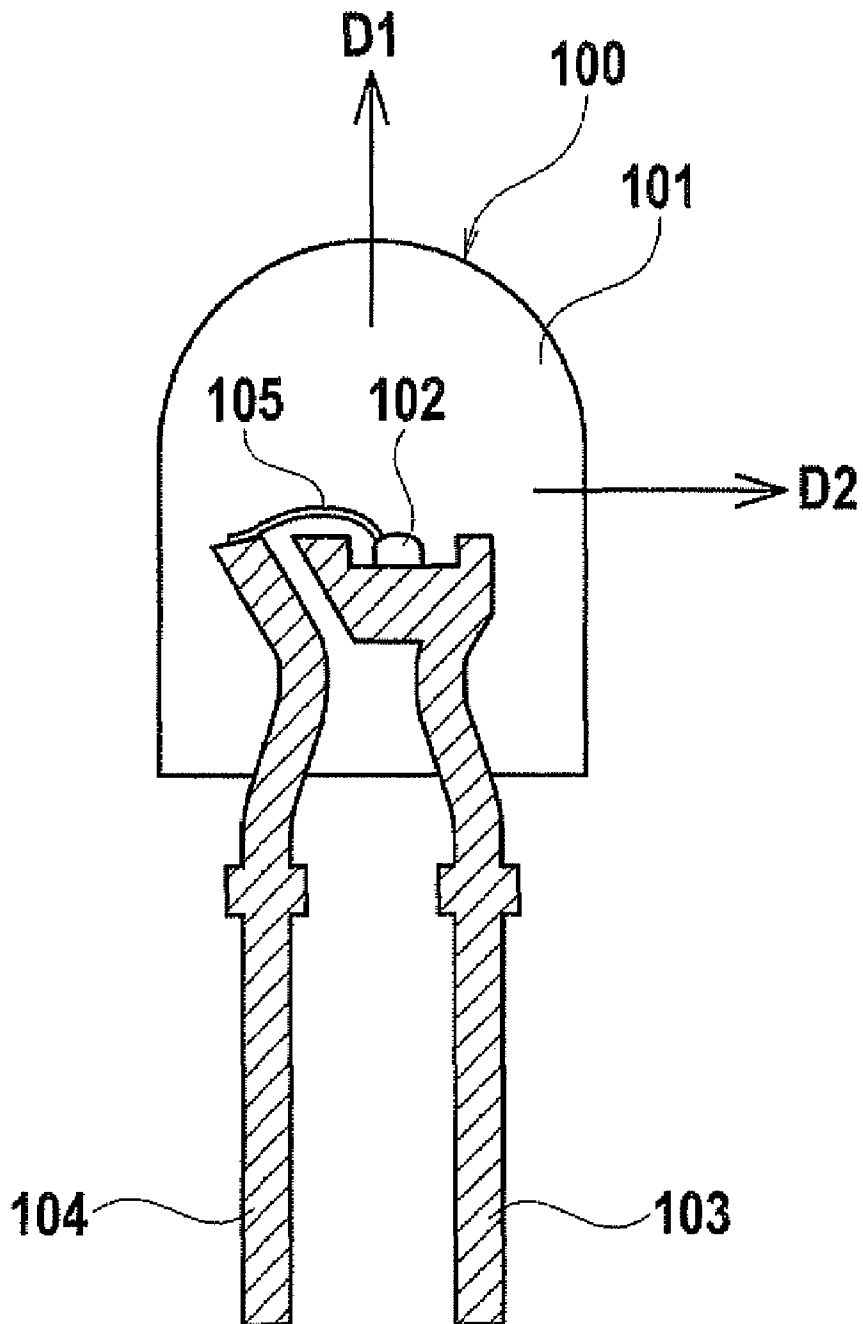
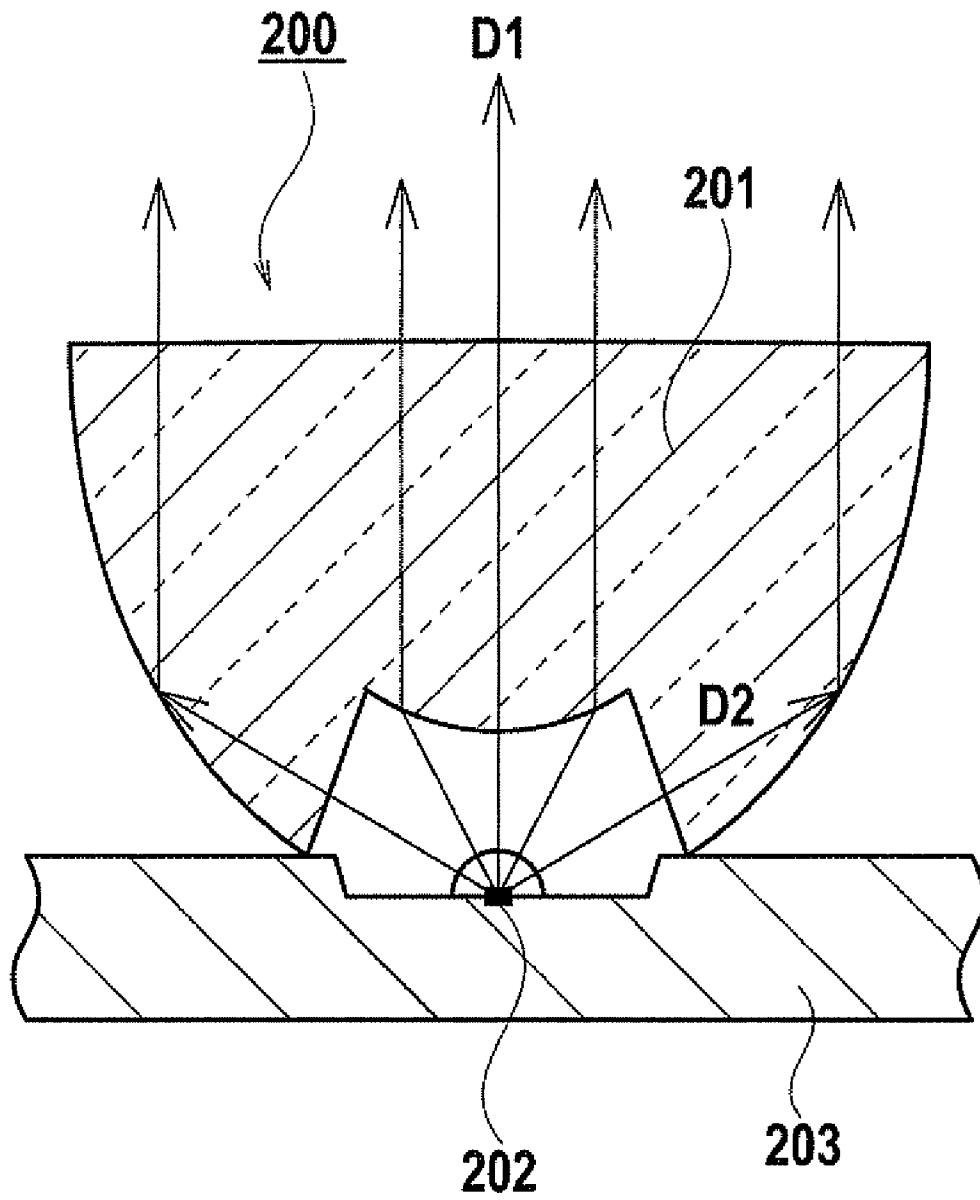


FIG. 26



# LIGHTING SYSTEM HAVING LENSES FOR LIGHT SOURCES EMITTING RAYS AT DIFFERENT WAVELENGTHS

## CROSS REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from the prior JP Applications No. 2005-300639 filed on Oct. 14, 2005, and No. 2006-258632 filed on Sep. 25, 2006, the entire contents of which are incorporated herein by reference.

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

This invention relates to a lighting system, and in particular to a lighting system including semiconductor light emitting elements and an optical unit which controls the light distribution. More specifically, the invention relates to a lighting system which includes light emitting diodes and an optical unit controlling distribution of light rays, and which is effectively applicable to illumination of retail premises, business premises, residences, and so on.

### 2. Description of the Related Art

In a lighting system using white LEDs (light emitting diodes) as a light source, a bombshell-shaped lens, a combined total-reflection lens or a fly-eye lens are usually used to control distribution of light rays.

Bombshell-shaped lenses are widely used for indicators. For instance, JP Publication No. 3065263 (Reference 1) describes a bombshell-shaped lens which is made of plastics and is constituted by an oval or circular part combined with a cylindrical part. Referring to FIG. 25 of the accompanying drawings, a lighting system 100 (an LED lamp) is constituted by a light emitting diode chip 102 embedded in a bombshell-shaped lens 101. The light emitting diode chip 102 is mounted in a lead 103, and one of main electrode terminals of the light emitting diode chip 102 is electrically connected to the lead 103. The other main electrode terminal of the light emitting diode chip 102 is electrically connected to a lead 104 using a wire 105. The bombshell-shaped lens 101 gathers most of light rays emitted by the light emitting diode chip 102 (light source), and leads the light rays forwardly in a narrow range (in an illuminating direction D1), thereby realizing a lighting system 100 which assures narrow light distribution.

With the lighting system 100, it is impossible to efficiently use light rays emitted in a direction D2 which extends round the illuminating direction D1 of the light emitting diode chip 2. Such light rays are of no use, which will affect efficient use of light rays emitted by the lighting system 100. Further, with the foregoing lighting system 100, the light emitting diode chip 102 is embedded in the plastic bombshell-shaped lens 101, so that heat generated therein cannot be effectively radiated. The lighting system 100 consumes a lot of electric power. Therefore, it is very difficult to use diodes which assure a large light intensity but produce a lot of heat. For the foregoing reasons, the lighting system 100 including the bombshell-shaped lens 101 seems unfavorable to applications in retail premises, business premise, residences and so on.

The following lenses assure large light intensities, and are being used in place of the bombshell-shaped lens 101 as described in: JP Publication No. H4-36588 (Reference 2); JP Laid-Open Publication No. 2003-281909 (Reference 3); U.S. Pat. No. 5,757,557 (Reference 4); U.S. Pat. No. 6,896,381 (Reference 5); JP Laid-Open Publication No. 2005-190954

(Reference 6); JP Laid-Open Publication No. H5-152609 (Reference 7); and JP Laid-Open Publication No. H7-99345 (Reference 8). References 2 to 4 describe combined total reflection lenses while Reference 5 describes a method of collimating light rays originated by the light emitting diode using a single lens, a single mirror or the like. Referring to FIG. 26, a lighting system 200 includes a combined total reflection lens 201 which is mounted on a light emitting diode chip 202 placed on a substrate 203. In the lighting system 200, light rays originated by the light emitting diode chip 202 in the illuminating direction D1 are collimated by a refracting lens. Light rays originated in the illuminating direction D2 which is around the illuminating direction D1 are reflected by the combined total reflection surface in the illuminating direction D1. Therefore, most of light rays emitted by the light emitting diode chip 202 in the whole direction are collimated in the illuminating direction D1, so that light rays can be used very efficiently. Further, heat generated in response to the light emission of the light emitting diode chip 202 can be radiated via the substrate 203, which enables the use of the light emitting diodes assuring large light intensities, and application to lighting systems requiring large light intensities.

Reference 6 describes a lighting system including a fly-eye lens, in which light rays can be illuminated onto a specific area. The lighting system can be thinned as a whole.

However, it seems that the following problems remain to be solved in the lighting system 200 including the combined total reflection lens 201. Generally speaking, a lighting system like the lighting system 200 uses a critical optic system which projects light rays in an infinite direction. If there is a color shade or luminance shade on the light source, it may be projected as it is onto an illumination target. A white light emitting diode commonly emits light rays using the following methods.

(1) As described in References 7 and 8, a yellow fluorescent object is placed around a blue light emitting diode. Some blue light rays are converted into yellow light rays, so that the blue and yellow light rays are combined to produce white light rays.

(2) A red light emitting diode, a green light emitting diode and a blue light emitting diode originate light rays, so that red, green and blue light rays are combined to produce white light rays.

(3) RGB fluorescent layers are placed around a near ultraviolet light emitting diode in order that near ultraviolet light rays are converted into white light rays via the fluorescent layers.

The method (1) assures light emitting efficiency which is approximately 30% higher than in the methods (2) and (3), and is practically preferable to lighting systems in retail premises, business premises, residences and so on where large light intensities are required. However, if the lighting system 200 using the combined total reflection lens 201 adopts the method (1), color shades or luminance shades of the blue light rays originated by the light emitting diode chip 202 and the yellow light rays originated by the yellow fluorescent substance are projected on the illumination target as they are via the combined total reflection lens 201. Therefore, it is very difficult to produce uniform white light rays. The method (2) also suffers from this problem.

Further, the combined total reflection lens 201 has a three-dimensional shape in which a refractive surface and a reflective surface are combined, and which requires high manufacturing cost (molding cost). The lighting system 200 will inevitably become expensive. Further, the combined total



reflection lens **201** has a complicated three-dimensional structure, and is not preferable to be manufactured in the shape of a module.

Still further, the light system using the fly-eye lens includes a collimating lens between the light emitting diode and the fly-eye lens. The collimating lens collimates light rays originated from the light emitting diode, and the collimated light rays are designed to have a distribution angle of below 30 degrees. However, since light rays outside the light distribution angle are not gathered and lost, they cannot be sufficiently efficiently utilized.

Since the fly-eye lens has a minutely bumpy surface, it may be easily contaminated, which will adversely affect efficient use of light rays.

This invention has been contemplated in order to overcome problems of the related art, and is intended to provide a lighting system which can reduce color shades.

A further object of the invention is to provide a lighting system which can promote efficient use of light rays as well as reduce color shades

#### SUMMARY OF THE INVENTION

In accordance with an aspect of the embodiment of the invention, a lighting system includes a first light source emitting first light rays; a second light source having a light emitting point partly displaced from the first light source and emitting second light rays whose wavelength differs from a wavelength of the first light rays; a first lens side which refracts and collimates the first and second light rays; a second lens side which includes a plurality of juxtaposed first lenticules and refracts the first and second light rays; and a third lens side which includes a plurality of juxtaposed second lenticules and refracts the first and second light rays refracted by the second lens side. In the lighting system, the second lenticules correspond to the first lenticules on the one-to-one basis; the first lenticules collect the first and second light rays on the second lenticules; and a part of a first illumination area of the first and second light rays refracted by one first lenticule and one second lenticule overlaps with a part of a second illumination area of the first and second light rays refracted by another first lenticule and another second lenticule.

In accordance with another aspect of the embodiment, a lighting system includes a light emitting diode emitting blue light rays; a fluorescent substance receiving the blue light rays and emitting yellow light rays; a Fresnel lens refracting and collimating the blue and yellow light rays; a first fly-eye lens refracting the blue and yellow light rays passing through the Fresnel lens; and a second fly-eye lens refracting the blue and yellow light rays passing through the first fly-eye lens.

#### BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

Like or corresponding parts are denoted by like or corresponding reference numerals.

FIG. 1 is a schematic view of a lighting system according to a first embodiment of the invention;

FIG. 2 is an enlarged cross section of a substrate on which a semiconductor light emitting element and a fluorescent object are mounted;

FIG. 3A is a perspective view of the fluorescent object of the lighting system in FIG. 1;

FIG. 3B is a cross section of the fluorescent object;

FIG. 3C is a top plan view of the fluorescent object;

FIG. 4 is a perspective view of a light distribution control lens (optical lens) of the lighting system in FIG. 1;

FIG. 5 is a cross section showing how to make a Fresnel lens as the light distribution control lens;

FIG. 6 is a graph showing the relationship between wavelengths and light emitting intensities of the semiconductor light emitting element and the fluorescent object;

FIG. 7 is a graph showing light distribution of a comparison example of the related art;

FIG. 8 schematically shows a configuration of a light distribution lens (fly-eye lens) of a comparison example;

FIG. 9 schematically shows a configuration of lenses of a critical illumination used for a light distribution control lens in the related art;

FIG. 10 schematically shows a configuration of lenses in a Kehler illumination used for light distribution control in the lighting system of the first embodiment;

FIG. 11 schematically shows a configuration of lenses in a fly-eye integrator illumination used for light distribution control of the lighting system of the first embodiment;

FIG. 12 shows the distribution of light rays in the lighting system of the first embodiment;

FIG. 13 schematically shows a structure of a lighting system in a second embodiment of the invention;

FIG. 14 is a top plan view of a light distribution control lens (Fresnel lens) of the lighting system in FIG. 13;

FIG. 15 is a top plan view of a light distribution control lens (fly-eye lens) of the lighting system in FIG. 13;

FIG. 16 is a top plan view of a light distribution control lens (flat lens) of the lighting system in FIG. 13;

FIG. 17 schematically shows a first structure of a lighting system in a third embodiment of the invention;

FIG. 18 is an enlarged view of an essential part of the lighting system shown in FIG. 17;

FIG. 19 shows the relationship between an angle of light rays of a refractive Fresnel collimator and an inclination angle of a lens;

FIG. 20 shows the relationship between an incident angle of a full reflection type Fresnel collimator and an inclination angle of a lens;

FIG. 21 shows characteristic curves for determining angles of the full reflection type Fresnel lens when a byte angle is constant;

FIG. 22 schematically shows a second structure of the lighting system in the third embodiment;

FIG. 23 schematically shows a third structure of the lighting system in the third embodiment;

FIG. 24A is a top plan view of an essential part of a light distribution control lens of a lighting system in a fourth embodiment of the invention;

FIG. 24B is a cross section of the light distribution control lens, taken along line 21B-21B in FIG. 24A;

FIG. 25 shows a structure of a lighting system having a bombshell-shaped lens in an example of the related art; and

FIG. 26 shows a structure of a lighting system having a combined reflection lens in another example of the related art.

#### DETAILED DESCRIPTION OF THE INVENTION

The invention will be described in detail with reference to embodiments shown in the drawings.

## [Structure of Lighting System]

In a first embodiment, a lighting system **1** includes a semiconductor light emitting element **10** (a first light source), a fluorescent object **20** (a second light source), a first lens **30**, and a second lens **40**. The first lens includes a first lens side **31** and a second lens side **32**. The second lens **40** includes a third lens side **41** and a fourth lens side **42**. The semiconductor light emitting element **10** originates first light rays. The fluorescent object **20** extends over a light emitting area of the semiconductor light emitting element **10**, receives the first light rays, and produces second light rays whose wavelength differs from a wavelength of the first light rays. The first lens side **31** collimates the first and second light rays. The second lens side **32** includes a plurality of first lenticles **321** which refract the first and second light rays refracted by the first lens side **31**, and are juxtaposed. The third lens side **41** includes a plurality of second lenticles **411** which refract the first light and second light rays refracted by the second lens side **32**, face with the first lenticles **321**, and are juxtaposed. In the lighting system **1**, the first lenticles **321** of the second lens side **32** collect the first and second light rays on the second lenticles **411** of the third lens side **41**. Further, a part of a first illumination target of the first and second light rays refracted by one of the first lenticles **321** and by one of the second lenticles **411** overlaps with an illumination area of the first and second light rays refracted by one of the first lenticles **321** and one of the second lenticles **411**. The first and second light rays originated by the lighting system **1** are projected in infinity onto an illumination target **50** and the second illumination target **52**.

The term "in infinity" represents a limit point where the first and second light rays originated by the light source are collimated. Actually, the limit point is sufficiently far from the lighting system **1**, e.g., on a desk, floor, wall or the like if the lighting system **1** is installed on a ceiling.

The lighting system **1** is designed to be applicable to illuminating retail premises, business premises, residences, and so on which require large light intensities. Therefore, the lighting system **1** includes the semiconductor light emitting element **10**, and the fluorescent object **20**. The semiconductor light emitting element **10** produces the blue light rays (whose wavelength is 400 nm to 500 nm). The fluorescent object **20** converts a part of the blue light rays into yellow light rays (whose wavelength is 500 nm to 700 nm, and which differs from the wavelength of the blue light rays). The blue and yellow light rays are mixed to produce white light rays. In this case, white light rays can be efficiently produced compared to the other light producing methods. FIG. 6 shows the relationship between a light emitting intensity and a wavelength of the blue and the yellow light rays. The abscissa denotes the wavelength while the ordinate denotes the light emitting intensity. Alternatively, the fluorescent object **20** may produce second light rays whose wavelength is a combination of the yellow and red light rays.

The semiconductor light emitting element **10** is preferably a blue light emitting diode (a semiconductor chip) in the first embodiment. Specifically, a blue light emitting diode mainly made of gallium nitride (GaN), zinc oxide (ZnO), or zinc selenide (ZnSe) is usable.

As shown in FIG. 2, the semiconductor light emitting element **10** is mounted on the substrate **11**. The fluorescent object **20** extends over top and side surfaces of the semiconductor light emitting element **10** in order to house the semiconductor light emitting element **10** therein. The substrate **11**

is constituted by a base **110**, an insulator **111** on the base **110**, a circuit pattern **112** on the insulator **111**, a reflector **113** having a reflective surface **113R**, and a recess **114** defined by the reflective surface **113R** and a bottom defined by a part (specifically, a part of surface of the circuit pattern **112**) of the base **110**.

The base **110** of the substrate **11** is made of a material having high thermal conductivity, e.g., an aluminum substrate, in order to effectively radiate heat generated in response to the light emission of the semiconductor light emitting element **10**. Alternatively, the base **110** may be made of a material having high thermal conductivity such as a glass epoxy resin, an engineering plastics, aluminum nitride and so on.

The insulator **111** prevents electric short circuits between the circuit pattern **112** and the base **110**, and is made of a silicon oxide film or a silicon nitride film which can assure a sufficient withstand voltage even if the semiconductor light emitting element **10** is thinned in order to reduce thermal resistance between the circuit pattern **112** to the base **110**.

Although a layout of the circuit pattern **112** is not shown, the circuit pattern **112** includes a first wiring and a second wiring. The first wiring is electrically connected to a main electrode terminal on the front surface of the semiconductor light emitting element **10**. The second wiring is electrically connected via a bond to a main electrode terminal on a rear surface of the semiconductor light emitting element **10**. In this embodiment, the circuit pattern **112** is constituted by three metal layers. A bottom layer of the circuit pattern **112** is directly deposited on the insulator **111**, and is made of a material having high electric conductivity and high thermal conductivity, e.g., copper foil. An intermediate layer of the circuit pattern **112** is placed on the copper foil, and is made of a nickel-plated substance having high reflectance. A top layer is placed on the intermediate layer, and is a copper-plated substance having high electric conductivity and thermal conductivity, and easy to be bonded onto the rear surface of the semiconductor light emitting element **10**. Alternatively, the circuit pattern **111** may be made of noble metal such as gold, silver or the like.

The reflector **113** defines the recess **114** in which the semiconductor light emitting element **10** is placed, and has a reflective surface **113R**, which reflects light rays (originated from the semiconductor light emitting element **10** in the direction **D2**) in the illuminating direction **D1** vertical to the surface of the substrate **11**. The reflective surface **113R** and the recess **114** can be easily molded, and has high light reflection energy, and is made of such plastics as polybutyrene terephthalate (PBT), polycarbonate (PC), or the like.

The fluorescent object **20** is made of yttrium aluminum garnet (YAG) or the like, which is dispersed in such transparent plastics as a silicone resin, epoxy resin, modified epoxy resin or the like, is filled in the recess **114** and is cured therein. Referring to FIG. 3A to FIG. 3C, the semiconductor light emitting element **10** has a size of 0.3 mm to 1.0 mm (i.e., one side of the light emitting diode chip). The fluorescent object **20** is in the shape of an inverted and truncated cone, which has a circular top with a diameter **L** of 2.5 mm to 3.5 mm, and a wall with a height of 0.5 mm to 1.0 mm.

Referring back to FIG. 1, the first lens side **31** and the second lens side **32** serve as a light distribution control lens, i.e., constitute an optical unit, and are positioned on opposite sides of the first lens **30**. The third lens side **41** and the fourth lens side **42** are opposite surfaces of the second lens **40**.

The first lens side **31** is placed to face with the semiconductor light emitting element **10**, and is curved outward toward the semiconductor light emitting element **10**, and

serves a convex lens. The first lens side **31** gathers the first and second light rays from the semiconductor light emitting element **10** and the fluorescent object **20**, and collimates the collected light rays in the illuminating direction **D1**. As shown in FIG. 1 and FIG. 4, the first lens side **31** is in the shape of a Fresnel lens having stepped concentric circles **31B**, and being thinner and flatter than a conventional lens of equivalent focal length as shown in FIG. 5. This makes the first lens **30** thinner.

The second lens side **32** is opposite to the first lens side **31**, and includes the first lenticles **321** which are curved outward toward the third lens side **41** of the second lens **40**. In short, the second lens side **32** is positioned between the first lens side **31** and the third lens side **41**, and faces with both of the first lens side **31** and the third lens side **41**. The second lens side **32** collects the first and second light rays which are refracted and collimated by the first lens side **31**, so that the light rays from the light source are focused on the third lens side **41**. As shown in FIG. 1 and FIG. 4, the second lens side **32** is a fly-eye lens in which the first lenticles **321** are arranged in the shape of a matrix, thereby making an aperture ratio smaller, and thinning the first lens **30**.

The first lens **30** is made of such plastics as acrylic or polycarbonate and so on, which has high optical transmissivity and is easy to be molded.

The third lens side **41** is positioned on a part of the second lens **40**, which is opposite to the fourth lens side **42**. The second lenticles **411** are curved outward toward the second lens sides **32**. As shown in FIG. 1, the first and second light rays refracted and collected by the second lens side **32** are projected in an infinite direction toward the illumination target **50**. In other words, the third lens side **41** is equivalent to a capacitor lens, and controls the light distribution. Referring to FIG. 1 and FIG. 4, the third lens side **41** is a fly-eye lens in which the second lenticles **411** are arranged in the shape of a matrix. Each second lenticle **411** corresponds to each first lenticle **321**. The first lenticles **321** are designed to have a small curvature radius in order to focus the light rays from the light source in a short distance to the second lenticles **411**. On the contrary, the second lenticles **411** are designed to have a curvature radius larger than that of the first lenticles **321** in order to transmit the light rays from the light source in infinity.

The fourth lens side **42** is opposite to the third lens side **41**, and faces with the illumination target **50**. The fourth lens side **42** is flat as shown in FIG. 1 and FIG. 4. Since the flat fourth lens side **42** is slow to be contaminated, it can prevent the lighting system **1** from lowering its optical efficiency even if it is used for a long time. Further, the fourth lens side **42** may be processed to promote light diffusion if necessary. Specifically, the fourth lens side **42** may be roughened, be covered with a coating material, or be applied a light-diffusing lamination film. The foregoing process enhances diffusion of the first and second light rays which are incident on the fourth lens side **42**.

The third lens side **41** and the fourth lens side **42** are made of such plastics as acrylic or polycarbonate and so on which have high light transmissivity.

#### [Light Distribution Control of Lighting System]

The distribution of light rays is controlled in the lighting system **1** as described hereinafter. First of all, the lighting system **200** of the related art will be described with reference to FIG. 26. The lighting system **200** includes a combined total reflection lens **201**, and emits white light rays using a blue light emitting diode **202** and a yellow fluorescent object. The lighting system **200** assures high light utilization efficiency.

FIG. 7 shows the distribution of light rays emitted by the lighting system **200**. The light intensity of the blue light rays is strong at a narrow light distribution angle near the center, and the blue light rays become yellowish at wide distribution angles near the periphery of the blue light rays. The intensity of the blue light rays is approximately two to four times strong compared with the intensity of the yellow light rays, depending upon a lens shape. When the light rays having the foregoing light distribution are controlled using the combined total reflection lens **201** of critical illumination type, the light rays will become bluish in a specific direction, and clear color shades or brightness shades will appear on the illumination target.

The foregoing phenomenon is caused because the blue light emitting diode **202** is much smaller than the fluorescent object **20**, i.e., the first light rays (blue light rays) and the second light rays (yellow light rays) are emitted at different positions.

On the contrary, in the lighting system **1** of the first embodiment, the first light rays (blue light rays) emitted by the semiconductor light emitting element **10** and the second light rays (yellow light rays) emitted by the fluorescent object **20** in response to the first light rays are refracted and collimated by the first lens side **31** (Fresnel lens). The collimated first and second light rays are illuminated onto the whole area of the second lens side **32** (fly-eye lens). The second lens side **32** refracts and collects the collimated light rays, and focuses the light rays of the light source on or around the third lens side **41** (fly-eye lens). The third lens side **41** casts in infinity slightly blurred light rays on the first lenticles **321** at the second lens side **32**. Therefore, the first and the second light rays can be substantially equally distributed onto the illumination target **50**.

In the light distribution control lens realized by the fly-eye lens shown in FIG. 8, if the light source **15** is not present on the optical axis (center axis) **La** which is common to the first lenticle **321** (2) and the second lenticle **411** (2), the light rays originated from the light source **15** pass through the first lenticles **321** (2) and focus on another second lenticle **411** (1) on the extension of the first and second small lenticles **321** and **411**. Such light rays are considered to be of no use. On the contrary, with the light system **1** of the first embodiment, the first lens side **31** (Fresnel lens) is placed between the light source **15** (semiconductor light emitting element **10**) and the second lenticles **321** of the second lens side **32**. The semiconductor light emitting element **10** is designed so that it seems to be present on the optical axis **La** which is common to the first lenticles **321**(1) and the second lenticle **411**(1); and the optical axis **La** which is common to the first lenticle **321**(2) and the second lenticle **411**(2). In short, the light rays originated by the semiconductor light emitting element **10** pass through the first lenticles **321** and focuses on the second lenticles **411**. This is effective in reducing light loss between the first and second lenticles **321** and **411**, and in promoting effective use of the light.

The lighting system **200** (the critical illumination) including the combined total reflection lens **201** differs from the lighting system **1** of the present invention as described hereinafter. For convenience, an ideal optical system is described assuming that a contact lens, capacitor lens, or parallel lens is free from such disturbances as irregular reflection or attenuation, which will be described later. In other words, the lighting system **1** may suffer from reduced use efficiency or light loss resulting from disturbances.

A critical illumination shown in FIG. 9 includes a light source **15** and an illumination target **50** which are optically conjugate (in image forming relationship). A capacitor lens

**45** is placed between the light source **15** and the illumination target **50**. If color shades or brightness shades are present on a light emitting surface of the light source **15**, similar color shades or brightness shade are also produced on the illumination target **45**. The lighting system **200** including the combined total reflection lens **201** and shown in FIG. **26** has a configuration substantially identical to the critical illumination.

On the contrary, in a Kohler illumination (shown in FIG. **10**), a capacitor lens **45** is optically conjugate with a light source **15** while a collector lens **35** is optically conjugate with an illumination target **50**. Even if there are color shades or brightness shades at respective light emitting points of the light source **15**, usually, direction dependency of colors or brightness changes relatively moderately. The collector lens **35** is relatively uniformly illuminated by the light source **15** so that the collector lens **35** is free from minute color shades. Light rays having luminance distribution in an aperture of the collector lens **35** are projected onto the illumination target **50**, so that light rays of the light source **15** are substantially uniformly illuminated onto the illumination target **50**. Further, when the collector lens **35** focuses the light rays of the light source **15** in the aperture of the capacitor lens **45**, the light rays passing through the collector lens **35** also pass through the capacitor lens **45**. This is effective in reducing light loss and promoting effective use of the light.

A further sophisticated Kohler illumination is called "a fly-eye integrator illumination", which is adopted in the first embodiment of the invention. As shown in FIG. **11**, each pair of lenticules **351** of the collector lens **35** and lenticules **451** of the collector lens **45** constitute the Kohler illumination. Light rays originated by the light source **15** are refracted and collimated by a collimating lens **36**. The collimated light rays are refracted and collected by the lenticules **351**, so that the light rays of the light source **15** are focused onto the lenticules **451**, and are projected in infinity by the lenticules **451**.

A size of an illuminated area of the illumination target **50** is sufficiently large in comparison with the whole size of the lighting system of the fly-eye integrator illumination system. Therefore, areas illuminated in infinity by respective lenticules **451** lap over, so that the same part of the illumination target **50** will be illuminated.

#### [Advantages of Lighting System]

FIG. **12** shows the distribution of light rays originated by the lighting system **1**. In FIG. **12**, the abscissa denotes light distribution angles while the ordinate denotes light intensities. The distribution angles of the blue light rays originated by the semiconductor light emitting element **10** (blue light emitting diode) are substantially the same as those of the yellow light rays originated by the fluorescent object **20** (yellow light emitting substance). In short, the light distributions of the blue and yellow light rays are the same, which enables the lighting system **1** to uniformly illuminate retail and business premises, residences and so on which require a large amount of light.

In the lighting system **1**, the first lens side **31** is the Fresnel lens, and the second lens side **32** is the fly-eye lens, which enables the first lens **30** to be in the shape of a thin plate. Further, the third lens side **41** is the fly-eye lens while the fourth lens side **42** is the flat lens, which enables the second lens **40** be in the shape of a thin plate. In short, the light distribution control lenses of the lighting system **1** can be thinned, so that the lighting system **1**, especially, the first lens **30** and the second lens **40** can be manufactured at a reduced cost. Further, a plurality of the lighting systems **1** can be arranged to have a modular structure.

It is assumed that the first and second lenses **30** and **40** are made by the injection molding. Plastic lenses are gradually hardened toward centers thereof from surfaces. If the plastic lenses are thin, they will be relatively free from shrinkage or distortion. The plastic lenses are slow to be distorted, and are protected against double refraction. Further, the plastic lenses can be easily molded and easily shaped in a module.

A time period for completely hardening the interior of plastic lenses is approximately proportional to a square of a thickness thereof, for instance. The foregoing combined total reflection lens **201** is thick, and takes time to be hardened. On the contrary, since the first and second lenses **30** and **40** of the lighting system **1** are thin, they can be hardened at short times, which means a shortened time for the injection molding. Therefore, the lighting system **1** can be manufactured at a reduced cost and a shortened time period.

Further, the fourth lens side **42** is flat, is slow to be contaminated, and is easy to be cleaned. This protects the lighting system **1** against contamination such as dust and soil, and prevents reduction of optical efficiency.

#### SECOND EMBODIMENT

In a second embodiment, a plurality of lighting systems **1** are assembled to have a module structure. Referring to FIG. **13**, each lighting system **1** is constituted by lighting units **1A** to **1F**, fluorescent objects **20**, reflectors **113s**, a first lens **30** and a second lens **40**. Each of lighting units **1A** to **1F** includes a semiconductor light emitting element **10**. In this embodiment, a total of six lighting units **1A** to **1F** are arranged in the shape of a matrix. Needless to say, the number of lighting units is not limited but may be determined as desired depending upon an amount of light and application.

A substrate **11** is commonly used for the lighting units **1A** to **1F**. As shown in FIG. **13** to FIG. **15**, the first lens **30** having the first lens side **31** (Fresnel lens) and the second lens side **32** (fly-eye lens) are molded as a single piece. Further, as shown in FIGS. **13**, **15** and **16**, the third lens side **41** (fly-eye lens) and the fourth lens side **42** (flat lens) of the second lens **40** are also molded as a single piece. Since the first and second lenses **30** and **40** are thin, they can be manufactured as a single piece in the lighting units **1A** to **1F**. The first and second lenses **30** and **40** are attached to and supported by a frame **60** at the periphery of the substrate **11**.

According to the second embodiment, the lighting units **1A** to **1F** can be manufactured as a module depending upon an amount of necessary light in retail or business premises, residences and so on.

#### THIRD EMBODIMENT

The lighting system **1** of the first or second embodiment is modified in order to promote efficient use of light rays.

#### [First Configuration of Lighting System]

Referring to FIG. **17**, a lighting system **1** of this embodiment is essentially configured similarly to the lighting system **1** of the first embodiment. The lighting system **1** includes a semiconductor light emitting element **10** (first light source); a fluorescent object **20** (second light source); first lens side **31**; second lens side **32**; and a third lens side **41**. The semiconductor light emitting element **10** originates first light rays. The fluorescent object **20** extends over a light emitting area of the semiconductor light emitting element **10**, and originates second light rays in response to the first light rays. A wavelength of the second light rays differs from that of the first light rays. The first lens side **31** includes a refractive region

11

311 for refracting and collimating the first and second light rays, and a reflective region 312 for reflecting and collimating the first and second light rays. The second lens side 32 is constituted by a plurality of first lenticules 321 which refract and reflect the first and second light rays, and are juxtaposed. The third lens side 41 carries on its surface a plurality of second lenticules 411, and refracts the first and second light rays which have been refracted by the second lens side 32. The first lenticules 321 and the second lenticules 411 correspond to one another on the one-to-one basis. The first lenticules 321 collect the first and second light rays onto the second lenticules 411. A part of light rays refracted by one of the first lenticules 321 and one of the second lenticules 411 overlaps one another with the second illumination area 52 of the first and second light rays refracted by another first lenticule 321 and another second small lens side 411 (refer to FIG. 1). The first and second light rays originated by the lighting system 1 are focused in infinity onto the illumination target 50, which is the first illumination area 51 and the second illumination area 52.

In the first lens side 31 of the first lens 30, the refractive region 311 is positioned on the center of the optical axis La of the first and second light rays. The reflective region 312 using the total reflection is placed around the refractive region 311. The refractive region 311 includes a round part 3111, and a first continuous prism 3112. The round part 3111 is at the center and around the optical axis La, and extends toward the semiconductor light emitting element 10 and the fluorescent object 20. The first continuous prism face 3112 includes stepped concentric circles 3112a and refractive surfaces 3112b. Each refractive surface 3112b is positioned around the round part 3111, and refracts the first and second light rays across the optical axis La (i.e., vertically). The refractive surfaces 3112b and the stepped concentric circles 3112a are alternately arranged.

The round part 3111 of the refractive region 311 forms an angle  $\theta$  between the optical axis La and the first and second light rays from the light sources (the light emitting element 10 and the fluorescent object 20). The angle  $\theta$  is 10 degrees or smaller, for instance. The round part 3111 is positioned in a range whose angle is nearly equal to an angle of collimated light rays. In the first configuration, the round part 3111 is in the shape of a cone whose apex angle is 150 degrees to 180 degrees.

The first continuous prism face 3112 is a Fresnel lens. As shown in FIG. 18, the refractive surfaces 3112b of the first continuous prism face 3112 forms an angle of 30 degrees or smaller with respect to the optical axis La around the light sources. In short, the first and second light rays from the light sources reach the refractive surfaces 3112b, and are collimated. The stepped concentric circles 3112a are brought in line with the optical axis La according to the principle shown in FIG. 5.

As shown in FIG. 19, the refractive surfaces 3112b are inclined with an angle  $\theta_U$ , which is ideally determined to satisfy the following, where  $\theta$  denotes the angle between the light rays from the light sources to the refractive surfaces 3112b and the optical axis, and  $n$  denotes a refractive index of a lens.

$$\theta_U = \tan^{-1} \left( \frac{n - \cos\theta}{\sin\theta} \right) \quad (1)$$

On the contrary, in order to efficiently use the first and second light rays originated by the light source at an angle of

12

30 degrees or larger, the reflective region 312 includes a second continuous prism 3121 constituted by incident sides 3121a receiving the first and the second light rays, and reflective side 3121b reflecting the incident first and second light rays. The incident sides 3121a and the reflective sides 3121b are alternately arranged. The second continuous prism 3121 is a Fresnel lens. The incident sides 3121a receive the first and second light rays from the light source, and are slightly sloped toward the refractive region 311. The reflective sides 3121b are inclined by 30 degrees or larger, and collimate the first and second light rays passing through the incident sides 3121a. The reflective sides 3121b are of the total reflection type.

As described above, the first and second light rays from the light sources are received in and refracted by the incident sides 3121a, are then totally reflected by the reflective sides 3121b, and are substantially collimated. As shown in FIG. 20, the inclination angle  $\theta_L$  between the incident sides 3121a and the reflective sides 3121b, and  $\theta_U$  are preferably determined to satisfy the following with respect to the angle  $\theta$  between the light rays from the center of the light sources and the incident sides 3121a and the optical axis La.

$$\cos(\theta + \theta_L) = n \cos(2\theta_U + \theta_L) \quad (2)$$

The refracted first and second light rays can be collimated and become parallel to the optical axis La.

The term "total reflection" is defined as follows. When passing through two transparent media having two different refraction factors, light rays are refracted at a border between the media. For instance, it is assumed here that one medium has a refractor factor  $n_1$  while the other medium has a refraction factor  $n_2$  (i.e.,  $n_1 > n_2$ ) and light rays reach the border at an incident angle  $\theta$ . When the incident angle  $\theta$  is small (i.e.,  $\theta$  is smaller than a critical angle), the light rays are refracted at the border and go forward. The larger the incident angle  $\theta$ , the nearer the refracting angle becomes 90 degrees. When  $\sin \theta = n_2/n_1$ , the refracting angle becomes equal to 90 degrees. In this state, the incident angle is equal to the critical angle. Further, if the incident angle  $\theta$  is larger than the critical angle, the light rays are completely reflected at the border. This phenomenon is called the "total reflection". In the third embodiment, since air having the refraction factor "1" is used as a medium in order to attain the refraction factor  $n_2$ ,  $\sin \theta = 1/n_1$  in the foregoing condition expression.

The apex angles of the incident sides 3121a and the reflective sides 3121b of the second continuous prism 3121 of the reflective region 312 are the same. FIG. 21 shows the relationship expressed by the formula (2).

A number of curves are depicted in FIG. 21 in accordance with incident angles of light rays. As can be seen from the graph of FIG. 21,  $\theta_U$  and  $\theta_L$  cannot be uniquely determined only when  $\theta$  and "n" are known. This is because one parameter remain unknown. When a byte angle is assumed to be a given value, i.e.,  $\theta_U + \theta_L = \text{constant}$ , is added,  $\theta_U$  and  $\theta_L$  can be uniquely determined. In FIG. 21, a straight line  $\theta_U + \theta_L = 45^\circ$  is added.  $\theta_U$  and  $\theta_L$  can be determined on the basis of a cross point of a curve related to a certain  $\theta$  and the byte angle  $45^\circ$ . If  $\theta_U + \theta_L$  is between  $0^\circ$  and  $90^\circ$ , a solution for any  $\theta$  is available. Therefore, the byte angle can be any value between  $0^\circ$  and  $90^\circ$ .

In the reflective region 312, apex angles formed by the incident sides 3121a and reflective sides 3121b of the second continuous prism 3121 are equal. A lowest point (which is formed by each refractive side 3112a and each reflective face 3112b of the first continuous prism 3112 of the refractive region 311) and another lowest point (which is formed by the refractive side 3112b of the stepped concentric circle 3112a

of the second continuous prism **3121** of the reflecting region **312** are present on the same plane (that is perpendicular to the optical axis La).

The first lens **30** can be easily fabricated when it is cut around the optical axis La using and rotating one expensive diamond cutter. In this case, either the first lens **30** or the diamond cutter may be relatively rotated. For instance, the diamond cutter preferably has triangular blades in order to shave off one incident side **3121a** and one reflecting side **3121b** of the second continuous prism **3121**. Further, the diamond cutter is also used to make the round part **3111** of the refractive region **311** and the continuous prism **3112**.

Further, in the first lens **30**, the round part **3111**, the first continuous prism **3112** and the second continuous prism **3121** have straight cross sections, so that they can be fabricated by the injection molding and using molds which are easily prepared.

The lighting system **1** of the third embodiment is as effective and advantageous as the lighting system **1** of the first embodiment. Further, the refractive region **311** and the reflective region **312** are placed on the first lens side **31**, so that the first and second light rays which are present around the first lens side **31** and are not refracted by the Fresnel lens can be reflected and collimated. This is effective in promoting efficient use of the light rays around the first lens side **31**.

#### [Second Configuration of Lighting System]

In the lighting system **1** of the third embodiment, the round part **3111** of the refractive region **311** may be curved on the first lens side **31** toward the light source like convex lenses. Refer to FIG. **22**. An apex of the refractive face **3112b** and the stepped concentric circle **3112a** of the first continuous prism **3112** and an apex of the incident side **3121a** and the reflecting side **3121b** of the second continuous prism **3121** may be present on the same plane. A mold for injection molding can be easily made.

The lighting system **1** having the second configuration is as efficient and advantageous as the lighting system **1** having the first configuration.

#### [Third Configuration of Lighting System]

The lighting system **1** of the third embodiment may be modified as shown in FIG. **23**. On the first lens side **31** of the first lens **30**, the highest point (position of an apex angle) formed by the refractive side **3112b** and the stepped concentric circle **3112a** of the first continuous prism **3112**, and the highest point formed by the incident side **3121a** and the reflective face **312** of the second continuous prism **3121** may be on the same plane. Further, a distance between the highest points and lowest points may be gradually increased. In this case, an area of the incident side **3121a** and incident angles can be gradually and centrifugally increased, which is effective in promoting efficient use of light rays.

The lighting system **1** having the third configuration is as effective and advantageous as the lighting system having the first configuration.

In the foregoing lighting system **1**, the round part **3111** of the refractive region **311** may be flattened so long as light rays can be collimated.

#### FOURTH EMBODIMENT

The lighting systems **1** of the first to third embodiments may be modified in order to further promote efficient use of light rays.

In a lighting system **1** of this embodiment, first lenticules **321** of the second lens side **32** (fly-eye lens) of the first lens **30** or second lenticules **411** of the third lens face **41** (fly-eye lens)

of the second lens **40** are more closely arranged as shown in FIG. **24A** and FIG. **24B**. Specifically, on the second lens side **32**, dead spaces (flat spaces) between the first lenticules lenses **321** are minimized so that they can be packed. The second lenticules **411** are packed similarly to the first lenticules **321**. The more densely the first lenticules **321** are packed, the more efficiently light rays can be utilized. The same holds true to the second lenticules **411**.

The second lens side **32** and the third lens side **41** are fabricated so as to satisfy the following formula, where “a” denotes pitches between the lenticules (fly-eye lens), “r” denotes a curvature radius of the fly-eye lens, and “h” denotes a height of the fly-eye lens.

$$r - \sqrt{r^2 - \left(\frac{\sqrt{2}}{2}a\right)^2} < h < r \quad (3)$$

In the lighting system **1** of the fourth embodiment, the first lenticules **321** of the second lens side **32** and the second lenticules **411** of the third lens side **41** can be very closely arranged, which is effective in promoting efficient use of light rays.

#### OTHER EMBODIMENTS

While the invention herein disclosed has been described by means of specific embodiments and applications thereof, numerous modifications and variations could be made hereto by those skilled in the art without departing from the scope of the invention.

For instance, the semiconductor light emitting element **10** of the lighting system **1** is the blue light emitting diode in the foregoing embodiments. Alternatively, a plurality of light sources whose light emitting points are different may be used in combination, e.g., green light emitting diodes and blue light emitting diodes may be used in order to produce white light rays. A semiconductor laser may be used in place of the semiconductor light emitting element **10**.

The first lenticules **321** and the second lenticules **411** are convex lenses in the foregoing embodiments. Alternatively, both or either the first lenticules **321** or the second lenticules **411** may be Fresnel lenses. Specifically, the first lenticules **321** may be Fresnel lenses while the second lenticules **411** may be convex lenses. In this case, the first lenses **30** can be made thinner, which is effective in improving yield, reducing a manufacturing cost, and shortening a manufacturing period.

The first lens side **31** is a simple Fresnel lens in the lighting system **1** of the foregoing embodiments. Alternatively, a complicated Fresnel lens may be utilized. Further, a Fresnel lens in which stepped concentric circles are independently designed may be used as the first lens side **31**.

Further, two or more lighting systems **1** of the first to fourth embodiments may be used in combination.

What is claimed is:

**1.** A lighting system comprising:

a first light source emitting first light rays;

a second light source having a light emitting point partly displaced from the first light source and emitting second light rays whose wavelength differs from a wavelength of the first light rays;

a first lens including a first lens side facing the first and second light sources, and a second lens side being opposite to the first lens side, the first lens side which refracts and collimates the first and second light rays, the second

15

lens side which includes a plurality of juxtaposed first lenticules and refracts the first and second light rays collimated by the first lens side; and

a second lens including a third lens side facing the second lens side, the third lens side which includes a plurality of juxtaposed second lenticules and refracts the first and second light rays refracted by the second lens side,

wherein each of the first lenticules has a convex surface curved outward toward the third lens side; each of the second lenticules has a convex surface curved outward toward the second lens side; each of the second lenticules correspond to each of the first lenticules on a one-to-one basis; the first lenticules collect the first and second light rays on the corresponding second lenticules, respectively; and a part of a first illumination area of the first and second light rays refracted by one of the first lenticules and one of the second lenticules overlaps with a part of a second illumination area of the first and second light rays refracted by another one of the first lenticules and another one of the second lenticules.

2. The lighting system defined in claim 1, wherein the first light source is a semiconductor light emitting element: and the second light source is a fluorescent object which extends

16

over a first light emitting area of the semiconductor light emitting element, and emits fluorescent light in response to the first light ray.

3. The lighting system defined in claim 2, wherein the first lens side is curved outward toward the semiconductor light emitting element.

4. The lighting system defined in claim 2, wherein the first lens side is a Fresnel lens which is curved outward toward the semiconductor light emitting element.

5. The lighting system defined in claim 1, wherein the first lens side is a Fresnel lens; and the second lens side is a fly-eye lens.

6. The lighting system defined in claim 1, wherein the first lens side is a Fresnel lens; and the third lens side is as a fly-eye lens.

7. The lighting system defined in claim 2, wherein the semiconductor light emitting element emits the first light rays whose wavelength is equal to a wavelength of blue light rays.

8. The lighting system defined in claim 2, wherein the fluorescent object emits the second light rays which are yellow or whose wavelength is equal to a combination of wavelengths of yellow and red light rays.

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